SKILL AND AGE

An Experimental Approach

by

A. T. WELFORD

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Members of the Nuffield Research Unit into Problems of Ageing at the Psychological Laboratory, Cambridge

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With a foreword by
PROFESSOR SIR FREDERIC C. BARTLETT

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FOREWORD

By

PROFESSOR SIR FREDERIC C. BARTLETT, C.B.E., F.R.S.

If anyone makes a study of the experimental investigations of the effects of ageing on human performance which were carried out prior to the work described in this Report he cannot fail to notice three things. First, the principal preoccupation was with the behaviour of the relatively elderly. Secondly, more attention was given to the disabilities of ageing than to any of its possible advantages. Thirdly, and most important, nearly all the measures which were collected, analysed, and studied were measures of simple bodily or mental functions carried out in isolation from all others.

The experimental approach which is the subject of this Report is different. It is not much concerned with behaviour in extreme old age. It treats ageing as a more or less continuous process with, possibly, certain critical age-ranges in which important changes are likely to become manifest. It is just as interested in discovering what older people can do better as in finding what they usually do worse. And the primary subject of its investigation is not any simple, isolated movement, or repetition of simple movements, whether of body or of mind. Its aim from the beginning was to discover how to collect, analyse, and interpret measures of *skill*, in which every item, every constituent movement, is partially the result of its relation to preceding and succeeding items in the cycle of movement necessary to the understanding and habits which the performer brings with him to his experiment.

The Report therefore has to be judged from two points of view: as a contribution to the fundamental psychology of human skill and of methods which make its accurate measurement or assessment possible, and as a study of the changes in skill which appear to be consequent upon increasing age. Only the first of these has, as yet, been carried to anything like final issues, and even in this there is obviously a great amount still to be achieved. How much patient and ingenious exploration has gone into the fashioning of the essential foundation only somebody who, like myself, has been able to watch the work from the beginning can properly appreciate.

Some things have, however, already become clear and demonstrable concerning the direct effects of ageing upon performance. We know that, for many forms of skill at least, the potential, and often the actual, level of achievement may suffer little, if at all, up to and even beyond what is now taken to be a normal retiring-age. But the characteristic manner of achievement may vary in important respects, and may begin to vary much earlier in life than has commonly been thought to be the case. The overall speed of most types of work may become slower, particularly through some change in the successive timing of constituent items. The characteristic ways in which incoming stimuli and outgoing actions are organized may alter. Contrary to general belief no great disturbance is found, given a healthy body, in relatively heavy work which can be performed at the operator's own speed. Comparatively little has so far been done with the more sedentary types of occupation involving in the main mental rather than physical effort. But a beginning has been made, and it seems likely that the general characteristics of change with age will be found to follow the same pattern.

Already some of these experimental methods and discoveries have been followed up in the field of organized industry, and it appears that many of the natural changes of occupation which accompany increasing age are exactly what would be expected if these basic laboratory studies are correct.

From this point on, it is likely that progress can be more rapid and more sharply directed. The fundamental methods have been shaped and their range and effectiveness demonstrated, so that they can be developed and extended in many ways. In the next period it may be expected that the significance of the studies for industrial and social well-being will become a primary objective. The psychological approach to the problems of ageing is only one of many. But it can be regarded as certain that, given adequate medical care and given a proper regard for the conditions of training and work which are appropriate for the particular age-ranges concerned, the great bulk of the members of any modern community ought to be able, over the whole of a full life-span, to continue to contribute to the productive skills which are essential in such a community, and to do so without undue fatigue or strain, but to their own happiness and satisfaction.

It is more than likely that every reader will consider that all that I have written so far in this Foreword is unnecessary. The detailed exposition which follows could as well, or better, stand by itself. But

there is one thing that I must add which nobody else could say. The team of students led by Mr. Welford has, during three and a half years which have been difficult in many ways, worked with rare harmony, enthusiasm, and insight. The credit for what they have done is theirs, and their achievements are a genuine co-operative effort. I am proud that they have worked as members of my Department.

May 1950

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PREFACE

THE Nuffield Research Unit into Problems of Ageing was started in 1946 with a grant by the Nuffield Foundation to the University of Cambridge. It was attached to the Cambridge Psychological Laboratory, with Professor Sir Frederic Bartlett as its Honorary Director. The terms of reference were wide, permitting the study of nearly every aspect of ageing, but from the outset it was clearly in mind that the Unit's main purpose was the study of changes of skill in middle and old age with a view to ultimate applications in industry.

Work during the first two years was slow. Not only were we groping after an understanding of our problem and methods of tackling it, but we were seriously hampered in two ways. First we found great difficulty in securing an adequate supply of subjects for our experiments, and second we suffered many changes of staff. The first of these difficulties is still with us, but the second, which was largely symptomatic of unsettled post-war conditions, has greatly improved.

Most of the work reported here dates from the years 1946–8. We have brought it to publication at this stage not because it represents our final word on any problem, but because detailed scrutiny of it during the past eighteen months has enabled us to attempt an interpretation which can act as a starting-point for further work. We have prefaced our report with a discussion of some theoretical aspects of ageing and of skill, hoping not only that by so doing we shall make clearer some of the ideas which have shaped and grown out of our studies, but that this too may serve as an approach to further work.

The reader may, perhaps, feel that many of our findings are already common knowledge and that in stating them we merit the criticism that 'a psychologist is a person who tells you what you know already in language you can't understand'. If he should think this, we feel bound in fairness to say two things in reply. First, opinion and common observation on the effects of age do show considerable variation from person to person. Second, it is the giving of system and background to phenomena which are well known that is the first essential of a deeper understanding, and a necessary preliminary to any practical measures.

Although it has been our first aim to present some of our findings and thoughts to other research workers, we have been mindful of the fact that ageing is a subject which intimately concerns everybody,

whatever his walk of life. We have, accordingly, tried to keep our statement as non-technical as possible. We have not always been able to avoid technicalities entirely, but we hope they have been reduced to a point at which they will not cause undue trouble to a reader not trained in psychology.

The Unit has worked very much as a team, and it is difficult to assign credit for the different pieces of work reported here to the various members. The names of those principally responsible in each case are, however, given below, together with the approximate dates when the work was done:

Experiment 1. MISS RUTH A. BROWN (1947).

Experiments 2 and 3. MR. J. SZAFRAN (1947–8). A preliminary experiment was carried out by MISS GILLIAN C. WEBB (1947).

Experiment 4. MISS RUTH A. BROWN (1948–9).

Experiment 5. The author (1947–8).

Experiment 6. MR. C. G. A. ALLAN (now University Assistant Lecturer in the Faculty of Moral Science, Cambridge) (1947).

Experiment 7. MRS. BETTY M. BERNARDELLI (now Assistant Lecturer in the Department of Philosophy, University of Otago) (1947).

Experiment 8. MR. A. B. CHERNS (now a Senior Scientific Officer at the Air Ministry) (1948).

Experiment 9. MR. H. KAY (1949).

Industrial investigations. MR. R. M. BELBIN and MRS. ANTONIA M. N. SHOOTER (formerly MISS SEWELL) (1948–9).

We wish to record our appreciation of the aid given in obtaining subjects for our experiments by the authorities of Impington Village College, the Cambridgeshire and Isle of Ely Territorial Army Association, the Polish Resettlement Corps Trade School at Fowlmere, the Polish Resettlement Corps Officers' Holding Unit at Mepal, and the Cambridgeshire Agricultural Executive Committee's Polish Hostel, the East Chesterton Over-Sixties Club, the Castle Old Folks' Club, and the Trumpington Ward Red Cross Old Folks' Club in Cambridge. We wish also to express our gratitude to the individual subjects for their co-operation.

The industrial studies were carried out under the sponsorship of the Panel on Human Factors of the Committee on Industrial Productivity, and were made possible by the generous facilities granted by the following:

W. H. Allen Sons & Co. Ltd., Bedford; Baker Perkins, Ltd., Peterborough; Lewis Berger (Great Britain) Ltd., London; Boden & Co. Ltd., Derby; Connolly Bros. (Curriers) Ltd., London; Creed & Co. Ltd., Croydon; The Dunlop Rubber Co. Ltd., Birmingham; A. C. Gill, Ltd., Nottingham; Harris Lebus, Ltd., London; William Hirst & Sons, Ltd., Nottingham; The Holt Hosiery Co. Ltd., Bolton; Johnson Matthey & Co. Ltd., London; Kodak, Ltd., Wealdstone, Middlesex; Morris Motors, Ltd., Oxford; Osram–G.E.C., Hammersmith; The Post Office Telephone Exchange, Cambridge; Pye, Ltd., Cambridge; The Royal Ordnance Factory, Chorley, Lancs.; The Skefko Ball Bearing Co. Ltd., Luton; Tootal Broadhurst Lee Co. Ltd., Manchester; A. Tunnicliffe & Son, Ltd., Long Eaton, Derbyshire; Vauxhall Motors Ltd., Luton; W. Whitehouse & Son (Nottingham), Ltd., Nottingham.

It is impossible to give adequate acknowledgement to the many individuals in these establishments who have assisted us in obtaining information, but especial thanks are due to Mr. L. V. Green of the Dunlop Rubber Co. for the help and guidance he gave in the early stages of our work.

We wish to record our gratitude to members of the Unit whose names do not appear on the title-page, and to other members of the Cambridge Psychological Laboratory for their generous help and advice. We would especially mention Mr. G. Baker, our workshop mechanic, who constructed most of our apparatus, Dr. A. Carpenter, Miss H. M. Clay, Dr. A. W. Heim, Dr. W. E. Hick, and Mr. J. W. Whitfield.

We are also indebted to Miss D. G. Rowlands for drawing some of the figures, and to the *British Journal of Psychology* for permission to reproduce Figure 1.1.

Finally our most sincere thanks are due to Sir Frederic Bartlett, to whose inspiration, guidance, and encouragement we owe more than we can adequately express.

May 1950 A. T. W.

I

INTRODUCTION

THE studies described here have been conceived within the framework of the research on the measurement and analysis of human skill which was developed in the Cambridge Psychological Laboratory during the war, and they represent an attempt to relate this work to the maintenance of efficiency by men and women in later middle age employed in industry. It is well known that older workers are in some ways at a disadvantage and in some ways at an advantage when compared with younger. Our aim has been to lay the foundations of an investigation into the nature of those abilities and disabilities which increase with age, with particular reference to the bearing these may have on

(*a*) the nature of the work for which people in later middle age are best suited if they are to maintain their efficiency and self-respect, and

(*b*) the most suitable methods of retraining those whose skills become redundant as the result of changes of industrial process or shifting emphasis in production.

Previous studies of ageing have usually measured changes of ability at particular tasks without offering any explanation of why these changes should have come about, or have tried to demonstrate the effects of the influences which obviously vary with age, namely, the maturation and subsequent degeneration of the physical organism and length of contact with the environment. Our aim as regards explanation has been intermediate between these two classes of previous work, while as regards description it has been more radical than either. We have attempted to go beyond the measurement of changes in attainment, but have not attempted to demonstrate the ultimate causes of them. Instead, we have tried to study the manner in which the attainments of the subjects of various age-ranges have been achieved, and thus to gain information about the mechanisms lying behind them, and to locate more precisely than has been done before some of the changes in *performance* associated with age.

We have, accordingly, avoided the mere accumulation of such information as could have been obtained with relatively little effort by using some of the ready-made 'mental tests' which are available. Also,

in setting up experiments we have not tried to measure any supposedly basic element of performance in pure and isolated form. Instead, we have taken realistic, complex tasks and attempted to produce meaningful analyses of them, splitting up the performance into component parts which can then be considered separately without the disadvantage of their having been removed from the larger whole in which they normally occur. We believe that this method, although initially slower at yielding tangible and definite results, is likely to be more efficient in the long term as leading to findings of greater generality.

This approach gives to the experiments described here a fourfold point. First, although they are very much of an exploratory nature and have, as yet, been done on too small a scale for any very firm conclusions to be drawn, one or two rather consistent trends have appeared in the findings. These trends provide evidence for what would seem to be an important locus of change in performance during middle and old age. Second, the experiments provide examples of methods for research into ageing which have an implication beyond the immediate purpose for which we have used them. Third, in the broader field of general experimental psychology, the techniques and ways of dealing with results that we have developed illustrate methods of research into the nature of skilled performances which are in certain important respects new. Fourth, from the standpoint of applied psychology, the experiments provide a framework for direct studies of performance by people of different ages working in industry. A preliminary study of this kind is described in Chapter VII.

Most of the experiments we have done so far have, unfortunately, been on abilities which appear to diminish with age, and indicate only by implication ways in which improvement occurs. We are anxious to make a more positive study of the ways in which increasing age brings improved performance. There are indications in our results of one important area in which this occurs, namely in tasks demanding care and accuracy, but further work is required. The main difficulty that confronts such work is that the abilities which appear to show improvement with age have not in most cases so far proved amenable to scientific investigation.

II

OUTLINE OF THE THEORETICAL PROBLEM

BROADLY speaking, popular current theories to account for the changes that come about with increasing age fall into two main types:

(*a*) That these changes are the result of the physical maturation of the organism from birth to early adulthood, and its subsequent degeneration—the physical organism in this instance being taken to include not only the body in general, but also the brain and nervous system and thus the 'mental' organism as well.

(*b*) That these changes are essentially due to environmental factors, the effect of which increases with the extent to which the organism is in contact with them, and therefore increases, with age.

It is clear that neither of these theories in its crude form is adequate, and that even if for some purposes it is possible to separate the physical nature of the organism and the environment and to treat of them separately, if we do so we make an abstraction which easily becomes very unreal. Physical characteristics and environmental forces cannot in most cases be meaningfully isolated. Any activity by an individual is the result of the interaction between physical characteristics and the environment, and it is with these interactions that we must deal if we wish to study human activity and experience.

Each interaction between the organism and its environment modifies the organism so that it confronts later environmental situations different from what it was before, and these modifications, in so far as they are enduring, must be modifications to the physical organism as defined above. What the organism is at any moment of time is therefore the result of a long chain of interactions stretching from birth or before up to the present, and in this chain hereditary maturation-degeneration factors and environmental influences are intimately and inextricably mixed.

We may, however, for practical purposes, and providing we remember what we are doing, dissect out of this chain various relatively constant and pervasive features which can, up to a point, be dealt with separately. In particular for our present study we may dissect out:

1. Certain bodily changes which characterize individuals of different ages.

2. Features of the environment both present and past which seem to exercise a general steering influence over individuals or groups of individuals for relatively long periods.
3. Methods of dealing with particular situations or problems or kinds of situations or problems.
4. As the organism uses its past experience to predict the future and thus as a basis for *anticipatory adjustments* of itself, we should add these to the above three factors as a fourth deserving of study.

We shall proceed to consider these factors in turn, and their probable effects that go with increasing age. In doing so it must be clearly recognized that we are merely outlining some tentative working hypotheses based on current doctrine in experimental psychology, on the findings of previous workers in the field of ageing, and on remarks and suggestions made in the course of numerous conversations that members of the Unit have sought from time to time with people of different ages, and with employers, managers, doctors, and others. Although these tentative hypotheses have been shaped by the results of the Unit's work to date, they must be regarded more as a guide to future research than as an interpretation of past work.

1. *Bodily changes*

The successive changes of bodily, including neural, structure which take place between birth and old age show clearly that, if the human organism is viewed as a piece of anatomical and physiological machinery, it rises to a peak of efficiency in the early twenties and thereafter slowly declines. It therefore seems inevitable to say that as regards bodily mechanism the progress from young adulthood onwards is essentially one of gradual deterioration.

Although these physical deteriorations may be easy to detect and in some cases easy to measure, their effects on performance seem far from easy to determine. It seems, however, as if the organism, when confronted by a situation, makes what use it can of the mechanism it has, so that any deficiency in the mechanism is at least partly overcome by a *change of method* of dealing with the situation. In other words, we can say the organism *compensates* for its deficiencies. Deficiencies of this kind would seem inevitably to limit the range of the organism's potential activity, so that we should expect them to lead to some restriction of actual activity. This is readily observable

in cases of extreme old age, but it is questionable how far it applies to the 'I can't do all I used' of middle age.

It is likely therefore that examination of what an organism suffering from such disabilities *achieves* in a complex task will reveal:

(*a*) That a few things which formerly could be done cannot now be done at all; i.e. the disability is such that no compensatory change is possible.

(*b*) That some things cannot be done as easily as they could before; i.e. the changes of method do not fully compensate for the deficiency. Former levels of achievement may be maintained, but only with increased effort.

(*c*) In some cases the compensatory mechanisms may be such as to make the total performance better than it was before.

It seems clear from this that measuring the physical deficiencies as such will not enable us to make any very accurate prediction of achievements at a complex task, and that the degree of degeneration will be a poor indicator of inefficiency. It seems necessary therefore, if we wish to study the effects of these deficiencies, to turn our attention from total achievements to the details of the methods whereby these are attained, and to make an analysis of the complex performance and examine the different parts thus abstracted from the whole. Such parts in a total performance are probably much more closely linked to anatomical and physiological features of the organism than is the total performance to which they contribute. In so far as these anatomical and physiological features change with age we may therefore expect to be able to detect certain uniformities of method within any one age-group. On the other hand, any deficiency in the anatomical and physiological mechanisms of the individual will cause him to use compensatory mechanisms in maintaining his performance. These compensatory mechanisms are likely to differ from one individual to another. We may therefore expect that the physical deficiencies associated with age will be accompanied by a decrease in the range of activities of any one individual but an increase in the variability between individuals. In any actual case we are likely to find both uniformities and increased variabilities associated with differences of age, and it is possible that the degree of uniformity or variability found in any one portion of a total performance within any age-group can give us some indication of its origin and consequent modifiability.

2. *Features of the environment*

Just as an individual has inevitably to live within the framework of his physical constitution, so he has to live within the framework of his physical and social environment, which we may therefore expect to find exerting certain restricting and channelling effects upon his activities. Three factors which may be considered mainly in environmental terms seem to be of special importance as likely to affect the performance of different age-groups.

A. *Social demands*

(i) *Family responsibilities.* It seems likely that such social demands as the need to support a family will exert a very considerable effect upon what a man is willing to do and how hard he is willing to work, although it is difficult to give this effect any quantitative demonstration. The incentive will be to some extent 'forward acting', i.e. it will tend to operate before the family becomes expensive and may die away before the children have actually become self-supporting, so that on the average we should expect to find its main effects powerful during the thirties and perhaps early forties, and tending to die away thereafter. It is probable that such incentives as this can operate without the individuals being aware of them, and that, in so far as they become socially conventionalized, their influence extends to those who do not actually possess family responsibilities themselves.

(ii) *Social prestige.* The desire to maintain his social position in the community will also probably exert a considerable effect upon what a man is willing to do, although again it is difficult to give this effect quantitative demonstration. Its effect is likely to reinforce and prolong the effects of family responsibilities, and in addition it is likely, since social prestige is something which a man builds up in the course of many years, that it will produce resistance to anything tending so to change the social pattern as to constitute a threat to his social position.

The exact effects of these factors upon performance are, of course, difficult to assess. We may expect, however, that though they will have little effect if any on what a man *can* do, they will tend to narrow the range of what he is *likely* to do, by concentrating his activities in the

service of certain ends directly or indirectly connected with family or social position.

Although in general they are likely to increase efficiency of performance, especially in the direction of increasing carefulness, accuracy, and the other qualities normally demanded in employment and normally associated with the term 'responsibility', they may not always do so. Especially in cases where family or social demands are greater than the individual's ability enables him to meet, there is likely to be frustration and conflict which may lead to the disruption of efficient skilled (in the widest sense) activity. On this hypothesis we should expect to find similarities between such disruption occurring among old men whose failing physical powers make them unable to meet the demands of their position in society, and that occurring among men in middle life whose responsibilities are in excess of their abilities.

B. *Popular beliefs about the abilities of different age-groups*

Research in other fields makes it exceedingly likely that popular beliefs of the type that 'older workpeople cannot make the pace' or that 'you cannot teach an old dog new tricks' exert a considerable effect upon the performances of men belonging to the age-groups to which they refer, even though the men concerned may be quite unaware of this influence and, indeed, may stoutly deny it.

Again, the influence on performance will probably be a restrictive one, and again it will restrict not so much what can be done as what is likely to be done or what a man is willing to do. The beliefs will act on the individual by setting up *expectations* regarding his performance which will lead to:

(i) A lowering and narrowing of levels of aspiration which will often be in conflict, and sometimes serious conflict, with his desires to live up to his responsibilities and position in society.

(ii) Compensation for disabilities which he does not actually possess or over-compensation for disabilities which he does possess, leading to or accentuating the effects on performance that we have suggested above as likely to follow from real disabilities, except that the over-compensation may in some cases lead to an *improvement* in overall achievement.

(iii) Questioning of the beliefs may lead an individual to 'examine himself' and bring into consciousness many habitual activities and skills which if undisturbed would have done their work

quietly and efficiently, but which break up on being thus subjected to scrutiny.

C. *Features of past environment*

The hypothesis that what an individual is at any particular moment of time depends upon a continuous chain of interactions between organism and environment, stretching back to birth or before, implies that we can never in any practical case equate the environmental backgrounds of different age-groups, because the changes in social, educational, and material conditions during the past century inevitably mean that the childhoods of different age-groups have been spent under different environmental conditions. The importance of this point is enhanced by the probability that not all portions of the chain of interactions are equally significant, but that it is these very childhood and adolescent portions of it that are in many ways of predominant importance.

As the influences of such early environmental conditions can only affect the present state of the individual via a long chain of intermediate experiences and activities, their effects on present actions will be complex and difficult to predict. We should expect, however, that in spite of considerable variation between individuals, they would tend to produce certain inter-individual uniformities which would be associated with particular generations of the present population. These uniformities are not strictly speaking an effect of age as such, but since they attach to present-day age-groups they must be taken into account if we are studying the differences between these groups.

3. *Methods of dealing with situations or problems*

In dealing with each environmental situation as it arrives an individual seems to use what may be thought of as a repertoire of methods and abilities which have been built up in his dealings with similar problems in the past. If this repertoire provides some ready-made means of dealing with the situation which proves adequate, this is used more or less without change. If, however, no ready-made means of dealing with the situation proves adequate, it seems as if some new means is built up and is thereafter available for dealing with future situations. The individual's ability is thus increased, or in other words the number of things he can do is increased.

We should therefore expect that, other things being equal, as age increases the number of things which it is possible for an individual to

do should become greater, and that his ability to deal with each new situation as it comes along should rise. Certain tendencies seem to operate, however, to modify this increasing ability and the rising efficiency which we should expect to go with it:

(*a*) Although the possession of an increased number of ready-made responses should lead to an increased chance of having one which is appropriate for dealing with any new situation which arises, it is likely also to lead to an *embarras de richesse* so that in any new situation there will tend to be a conflict of response-tendencies which will produce hesitation, disorganization, and confusion. This should particularly be the case if anything happens to lower powers of discrimination.

(*b*) Although in the course of experience an individual will learn how to do an increasing number of things and what to do in an increasing number of situations, this process consists not only in learning what to do, but also what *not* to do in any particular situation. In other words, value judgements are made about actions: some things are recognized as *worth* doing, others as not. In one sense, of course, knowing what not to do, or what is not worth doing, is just as much a positive ability as knowing what to do. From the point of view of one studying overt behaviour, however, the two are different, and while learning what to do may increase the number of things which *can* be done, learning what not to do will greatly reduce the number of things *likely* to be done or which an individual is *willing* to do in any situation.

From this we may expect that with increasing age should go, other things being equal, an increase of skill in dealing with recurrent situations, but that this should be accompanied by an increased stereotyping of the method employed.

(*c*) It seems that in many cases certain methods or features of methods which have been found successful in dealing with a particular type of situation 'work loose' from their particular setting and become general tendencies or methods which are applied in dealing with a wide range of situations, and may come to colour almost the whole of an individual's activity. There are thus built up in an individual certain dominant responses or modes of response which tend to be applied to all types of situation and problem whether they are appropriate or not. They will

obviously make for increased uniformity of activity within any one individual, but are likely to lead to increased variability between individuals in a group. Their relationships to age are difficult to predict. Inasmuch as they are built in the course of experience, we should expect their effects to increase and harden with age. Further, we should expect these generalized tendencies to increase in importance as physical disability called compensatory mechanisms into operation. They seem, however, to be in opposition to the tendencies noted in the previous paragraph. It would seem that investigation of the conflict between these two kinds of tendency is of major importance to any study of human efficiency, especially as between persons of different ages.

4. *Anticipatory adjustments*

In any real-life situation a great deal, perhaps most, of what an individual does is in the nature of making responses which are in preparation for or anticipation of things which will happen in either the near or remote future. It seems as if the pattern of action for dealing with the future stimulus is laid down in advance so that either, when the stimulus arrives, it triggers off a pre-formed response, or the response is begun before the stimulus actually arrives. These anticipatory adjustments must inevitably be dependent upon past experience and, other things being equal, may therefore be expected to become more complete and better formed as age increases. It seems probable that it is by means of such anticipatory mechanisms that a large measure of compensation for physical defect is carried out by older persons. If this is so, we ought to be able to detect larger differences between age-groups in situations to which anticipatory adjustments cannot be made than in situations where they can, and it is probable that we should find older people voluntarily seeking a predictable environment.

III

ON THE NATURE OF SKILL

THE foregoing discussion has been concerned with the changes that come with age in terms of people and their relationships with their environment. We now turn to a more detailed consideration of the mechanism of skilled activity within an individual.*

We may think of the chain of processes which leads from a pattern of stimulation—a 'stimulus' as it is termed—falling on the sense-organs to the resulting behaviour as being in two parts. First, there are what may be called the *receptor* processes which have to do with the interpretation of the incoming stimulus, and second there are what may be called *effector* processes which shape the resulting action. In these terms, performance which can be called skilled would seem to possess three characteristics:

A. It is essentially the building of an organized and co-ordinated activity in relation to an object or display, and thus involves the whole receptor-effector chain.

B. It is learnt, in that the understanding of the display and the form of the action are built up gradually in the course of repeated experience.

C. It is serial and 'dynamic' in the sense that, within the overall pattern of a skill, there is a constant interplay between the receptor and effector functions and vice versa. Each part from second to second is dependent upon the last and influences the next.

Within any skilled performance these characteristics are inextricably bound up together. We discuss them here separately for convenience, but would emphasize that in doing so we introduce some artificiality. In order to gain an adequate view of the nature of skill no one characteristic can be considered apart from the others.

* Although the writer must take full responsibility for the views expressed in this chapter, they owe a very great debt both directly and indirectly to Sir Frederic Bartlett. It has been impossible to make detailed mention of sources in the text, but some of Sir Frederic Bartlett's published statements are listed in the references.

A. THE RECEPTOR-EFFECTOR ASPECT OF SKILL

The mechanisms of the receptor side

Skilled performance would seem in the first instance to depend upon two important principles of what may be broadly termed perception: first, that perception is essentially an *organizing process*, and second that in this process *past actions and experiences* play a leading role. We will deal with these two principles in turn.

1. *Organization in perception*

Between the receipt of stimuli by the sense-organs and the attainment of meaningful perception it appears that a chain of processes occur which are of considerable complexity, although often they take place so quickly that they are quite unconscious and perception appears to be 'immediate'. The broad fact that these are organizing processes is obvious enough. For instance, in visual perception the incoming data from the eyes are integrated, grouped, and ordered so that normally we see not just a mosaic of more and less stimulated points, but coherent objects which have form and structure. It is also obvious that normally we do not perceive with only one sense at a time, but that data from different senses are organized together, and that the resulting perception, although it is predominantly, say, visual or auditory, has been partly shaped by stimuli coming through many other sensory channels.

The exact details of this kind of organization are less certain but, nevertheless, fairly clear. It appears that the process of grouping and ordering the data involves—perhaps we should say consists of—the selection of some data as dominant and important, while the rest are relegated to the background and more or less neglected. This selection goes hand in hand with an integration of the selected data into *organized wholes*. Data thus organized are no longer treated as complexes compounded out of a multitude of separate elements, but as *single units*. The perceived wholes are thus in a very real sense 'simpler' than the stimuli giving rise to them. Psychological simplicity is, in fact, not the same thing as objective simplicity, but is essentially dependent upon the degree to which the data can be organized into larger units of this kind.

It appears that such an organization of the data is by no means the end of the perceptual process but that it is often—probably typically

—followed by one or more of three further types of organizing activity:

(*a*) A unitary whole which has been built up may be analysed into parts, as when we examine an object in detail. This analysis, although it involves breaking up a whole into smaller units, is not simply the reverse of the unifying process. Each of the parts is itself a unified whole, and each is still recognized as belonging within the framework of the larger whole out of which it has been analysed.

(*b*) Certain features of the whole may be abstracted and become perceptual units on their own. For instance, when reading a passage of prose we may become aware of features such as style.

(*c*) A number of unitary wholes may themselves be subjected to further processes of selection and integration which result in the formation of still larger units, as when reading we integrate words into sentences, sentences into paragraphs, and so on.

Although perceptual units built up in these ways may appear in consciousness as 'immediate' they often result from the integration of data which are not all present at the same instant, but which extend over a considerable period of time. In reading, for instance, the material organized into a paragraph has taken an appreciable time to observe. In perceiving an object which is too large to observe at a single glance we are putting together data from many individual glances which may have taken place over several seconds or even minutes. Some perceptual units, such as musical themes or visually seen movement, have indeed an essentially temporal character, the perceived wholes being by their very nature configurations in which time is a necessary dimension.

It seems that in many cases several stages of such organization are passed through on the way to full meaningful perception. The number of stages typically occurring probably varies somewhat between individuals and within the same individual on different occasions. Often they occur, as we have already said, very rapidly. Often, however, they take a considerable time, so that it is impossible to draw a hard and fast line between perception and thinking.

Whether rapid or slow, perception seems to involve mental activity and effort by the observer, so that the attainment of meaningful perception is not a mere process of 'registration', but is essentially a kind

of *response* by the observer to the material presented. We may conveniently call this a *perceptual response* to distinguish it from the overt action which may be taken in dealing with the presented material once it has been perceived. This perceptual response appears to be intermediate between the stimulus and overt action. It seems thus to stand at one and the same time in the relationship of response to the 'stimulus' and of stimulus to the 'response'.

2. *The role of past experience*

Some of this organization may be the result of the hereditary constitution of the organism. Certainly hereditary constitution sets some *limits* to the organization which takes place—i.e. we cannot do what we have no inherited potentiality for doing. But it is clear that for almost all important purposes organization at each stage of the perceptual process represents the application to the stimulus of material brought by the observer to the present situation from the past. In precisely what form this 'past' is available for use in the present is not known, but a number of important principles of the *manner in which it is used* are known with fair certainty. In particular:

(*a*) It may, especially when the data are familiar, be used *immediately* and without any intervention of consciousness. But in many cases, especially in dealing with data which are in some way novel, there seems to be an active search for terms of past experience which are 'fitting' or 'appropriate', and there may be use of images, searching for analogies, and a considerable amount of trial and rejection before satisfaction is reached.

(*b*) Even the simplest cases of relating present data to material which has gone before do not represent a straightforward precise matching of present and past material in the manner of fitting a present 'picture' exactly to one which has been experienced before. The stimulus produced by an object seen on two successive occasions is never quite the same. Even if the greatest care is taken to ensure that the original conditions are reproduced on the second occasion there will be some differences, and in most everyday conditions these differences are gross—for instance, even if the same object is being seen a second time it is seen from a different angle or in a different light. When the object seen on a second occasion is not the same as that seen on a first, but only resembles it in certain ways, these differences are obviously greater still. Indeed, in many if not most practical cases,

the process of relating present to past is not a matter of establishing identity at all, nor even of noting a degree of similarity or difference, but of setting something in relation to other things very unlike itself.

The process of relating is thus seldom, if ever, the mere aligning of what is present with something past which stands on its own, but is essentially the incorporating of what is present into an organized framework or setting of past material which is very much more extensive than the present stimulus and has been built up largely from objects and relationships very different from the stimulus concerned.

This framework or setting is both spatial and temporal, so that:

(i) an object is perceived as located in space, e.g. in a room or in relation to other objects such as the controls of a machine; and

(ii) events are perceived as localized in time, and series of events can be perceived as forming sequences and rhythms;

(iii) some kind of simultaneous spatial and temporal reference enables movement and causal relationships to be perceived.

(*c*) It is this setting of incoming data in a larger framework that gives them significance or *meaning*. It must be emphasized that although the data are related to what has gone before, the significance they gain is not only in terms of past events and a present setting. From our present frame of reference we are able to extrapolate future events. Meaning is thus not only backward-looking, but also has a forward-looking aspect which leads to anticipation and expectation. These have two important effects. First, action taken as the result of the attainment of meaningful perception usually has reference not to the state of affairs immediately present, but to the state that is expected to exist in the future, as for instance when, in driving a car, adjustments of the controls are made, not to the present positions of other vehicles on the road, but to the positions they will occupy a few seconds hence. Second, action is often prepared before the situation it is designed to meet has appeared. We watch out, as it were, for a stimulus which, when it comes, triggers off a pre-formed response.

(*d*) Each new perceptual response leaves the observer different from what he was before, so that the 'past' which he brings to deal with any new stimulus is in some way changed. The amount of change may, of course, be either small or large and will depend to some extent on the time-scale involved—a series of small changes from second to second may add up to a large change over a longer period. Whether small or great, however, it appears not to be due to the mere addition of

another experience to a 'stock' already existing. The past experience brought to deal with any incoming stimulus seems not to consist of an aggregate of past impressions, but appears to exist in an organized or *schematized* form which is affected by each new impression in a manner which can be compared to the *modification* of a 'plastic' model.

The mechanisms of the effector side

The integration of incoming data with some kind of schematic representation of what has gone before constitutes what we have termed a *perceptual response*, the making of which marks the completion of the chain of processes on the *receptor side*. At this point it would appear that a new series of events begins, initiated by the perceptual response which, as we have said, stands in the relationship of *stimulus* to effector action.

It would seem fairly clear that this second chain of events contains a series of stages which are in an important sense the reverse of those leading from an external stimulus to the perceptual response, i.e. there is a transition from integrated perception to detailed muscular movements. The nature of the events on the effector side is not at all well known—no doubt because they are usually unconscious—but it seems clear that they involve a progressive *differentiation* and *particularization.*

The first of them is probably some kind of general orientation or *attitude* which determines in broad outline what is to be done. Next, perhaps, come what may be called *general methods* of dealing with the object or situation concerned, and these are followed by particular 'knacks' and dexterities which in turn bring into play detailed muscular movements.

It should be noted that throughout the functioning of the effector side there seems again to be an organizational quality which is similar in several important ways to that of the receptor side. In particular:

(*a*) At each stage there is the use of pre-existing organized patterns of response. As with the receptor side, some of these may be innate; but it again seems clear that, though their limits are set by innate capability, this limitation is in most cases trivial compared with the influence of past learning and experience.

(*b*) The attitudes, methods, knacks, and so forth which are brought into play in the building of effector action show a

generalized quality in that they do not lead to exact stereotyped muscular movements. The actual movements made on any occasion are adapted to the requirements of that occasion, and, as these requirements are never exactly the same twice, the precise way in which the actual movements occur varies from one occasion to the next.

(c) The organization of muscular movements produced by the effector side has a reference which is not only spatial but also temporal, so that movements occur not as isolated units but bound into sequences. This is especially noticeable when actions are performed in a rhythmical manner, but is an essential characteristic of all manipulative operations and, indeed, of all bodily movements except the very simplest reflexes. In this connexion it is to be noted that, just as a series of stimuli may lead to a single perceptual response, so a single perceptual response may lead to a series of actions.

B. THE LEARNT ASPECT OF SKILL

From what has been said of the receptor-effector aspect of skill it will be clear that when a man meets a situation or carries out an action he necessarily and inevitably does so in terms of what he brings to it from previous experience. When he is meeting the situation or carrying out the action for the first time, he will have to build up his manner of doing so from a past experience which has been shaped by other situations and actions, some of which will be relevant and some not, so that success will depend to a great extent upon the way in which he selects from various alternatives. When he has to do the same thing again, however, the case is very different, because the past experience he brings will have been modified by his experience of the first occasion. In other words, learning has taken place.

The effects of meeting the same situation repeatedly are complex, and a number of variables, such as the time elapsing between one occasion and another, have been shown to influence them. For our present purpose, however, the points to be noted are, first, that the organization carried over from one occasion to another tends to become firmer and more complete the more it is used, and second, that although the organization undergoes considerable modification with repeated use, the way in which the task is performed the first time it is met may largely determine the manner of its performance

subsequently (Welford, Brown, and Gabb 1950). In relation to studies of ageing this means that if we are to understand present performance by older people fully it may be necessary to go a long way back into the past, to a time when industrial, social, and other demands were considerably different from what they are today.

It appears that the carrying over of organization occurs on both the receptor and the effector sides, so that a subject in learning a skill acquires gradually both an increased comprehension of the data presented in the task and an increased facility in executing the necessary actions. It further appears to occur at various levels on both sides, so that the skill that is built up has typically some relatively specific and some relatively generalized features.

The building of a stable organization in the course of repeated performance renders more meaningful the sense-data the subject gets when performing a skill. This appears to lead to two important results:

(*a*) He makes better use of sense-data and is therefore able to obtain the same performance with less data than he did before. For instance, he may be able to carry out by touch alone a task in which he formerly needed both to see and to feel the objects he was handling (see Experiment 3).

(*b*) He acquires a greater ability to anticipate future data and to plan actions ahead. As a result the skilled performance becomes smoother and speed increases without, however, any appearance either subjectively or objectively of hurry.

A considerable amount of evidence has been accumulated in recent years that, at least in certain tasks such as following a moving target, the number of discrete receptor-effector units which can be handled is only about two per second (e.g. Hick 1948, Vince 1949). Skilled typists and morse-operators execute the individual movements of printing letters or making dots and dashes very much faster than this, and it seems certain that they can do so only by building their performance into 'word units' so that a number of letters can be dealt with as a single stimulus or response. Evidence of this kind suggests that, together with the lessening of dependence on external data, there goes an increase in the size of the perceptual and response units. It seems clear that, like increase of anticipation, this process contributes to the smoothness of skilled performance and is often responsible for a substantial rise in speed.

As the learning of a skilled performance becomes more complete, there tends to be a dropping-out of conscious control, and possibly of some of the stages in the receptor and effector processes. These changes also appear to have the effect of speeding up the skilled performance and making it more efficient in the sense that it is carried out with greater economy of effort.

For the study of ageing, the learnt aspect of skill appears to be of especial importance. While older people seem less capable than younger of building up new skills, they can often carry on with a high degree of efficiency a skill already learnt.

C. THE SERIAL AND DYNAMIC NATURE OF SKILL

Except in the simplest reflexes, and often not even then, human activity never consists of discrete stimulus-response chains. Rather it is to be conceived as involving a constant stream of incoming data and of outgoing effector actions, all interconnected in the sense that the subject always to some extent observes the results of his own actions.

This interconnexion would seem to depend on information derived from three sources:

1. Actions of a manipulatory kind, by affecting external objects, modify the data fed into the receptor side. Actions of a non-manipulatory nature, such as the subject changing his position without doing anything to an external object, nevertheless change his relationship to external objects and thus similarly modify the data fed into the receptor side.
2. The muscular contractions and relaxations and the changes of posture involved in taking action modify the proprioceptive stimuli inevitably accompanying any external stimulus, and thus further modify the data fed into the receptor side.
3. It is probable that there are some direct connexions in the brain from the effector side back to the receptor side, although their existence and functioning have never been directly proved. Such connexions would enable some kind of data derived from central effector functioning to be fed into the receptor side without any necessary involvement of the peripheral musculature or overt action.

As a result of information fed back in these ways there appears to be a mixing of receptor and effector processes, so that not only is effector function dependent upon receptor, but receptor function is in a considerable measure determined by effector. In particular:

(*a*) attitudes which result from a perceptual response tend to produce a selective orientation towards subsequent stimuli so that the field of attention is narrowed and the observer is set to organize incoming stimuli in a particular way;

(*b*) in consequence of this, *each response does in a very real sense grow out of the responses which have gone before*, so that receptor and effector functioning must be regarded not as a collection of discrete acts, but as a single continually developing activity.

The effect of this information fed back from the effector to the receptor side may be regarded as either

facilitatory, as when the observation of the results of action provides encouragement to continue that action, or

inhibitory, as, for instance, when a task has been achieved or a movement is seen to have 'gone far enough', action tends to stop or change.

Whether the effect is facilitatory or inhibitory, the whole system of receptor and effector interaction appears to be analogous in many important ways to the *dynamic feedback* systems met in certain kinds of electronic and mechanical apparatus, such as regeneration and degeneration in radio sets, governors on steam-engines, and mechanically assisted steering-gear on ships.

By analogy with such mechanisms, human behaviour in which there was a predominance of facilitatory feedback would tend to be erratic and clumsy—the reverse of what is normally regarded as skilled. For performance to be skilled in the sense of being smoothly efficient it would seem that there must be a predominance of inhibitory feedback.

Inhibitory feedback gives to skilled performance two very important characteristics:

(i) To the extent that information about the results of action is available, action in relation to any external object tends to be 'pulled into line', i.e. it is more closely related to the *object* than to any momentary variations in the *subject*.

(ii) The subject's performance tends to remain constant in the face of disturbing influences, so that variation of the conditions under which a task is done has, within limits, little effect on achievement. One way in which this tendency shows is that *compensation* occurs in the face of difficulty. For instance, there may be changes in *method* of achieving an end, although

the end achieved remains the same. The importance of this for the experimental study of complex performance is that the components of the subject's performance are likely to vary to a relatively greater extent than does his total achievement.

It is, of course, to be emphasized that compensation of this kind will occur only when the task is such that the subject's capabilities are not fully stretched under the easiest conditions, and when the conditions are not so adverse that even the simplest task can be performed only with great difficulty. For adequate compensation to occur the subject must be working within his capabilities, and the external conditions must be within the limits of tolerance. Recent work suggests strongly that, as the difficulty of a task increases or as the external conditions become more and more adverse, performance remains relatively steady up to a point, but that after that point compensatory tendencies cease to be effective and performance deteriorates rapidly (e.g. Mackworth 1950).

Finally, we may note that the serial and dynamic aspect of skill, like the other aspects we have surveyed, is essentially a process of relating what is present to something that has gone before. The difference between this and the other aspects is one not so much of kind as of time-scale. The past which is linked to the present in perception and in learning is often very close to the present—indeed, it may be so much so that it forms part of the present in our experience—but it may also derive from a time days or even years ago. The serial and dynamic nature of skill essentially represents the linking of the present to the immediate past from one second to another.

LOCI OF CHANGES IN SKILL

It is clear from the foregoing that changes in skill for better or worse may be located in many different mechanisms. Of these, however, the peripheral receptor and effector organs are probably of only minor importance. Well-formed efficient sense-organs and muscles will favour the establishment and maintenance of skill, and impairment of either will tend to cause its breakdown, but a great many experiments and clinical observations on both animals and human beings have shown that there can be impairments of both sense-organs and peripheral effector organs with relatively little loss of skill.

Much more important would seem to be the central receptor and effector mechanisms concerned with the organization of data and the shaping of action. For instance, any failure to organize incoming data

will result in these data providing an inadequate basis for full meaningful perception and subsequent action. Again, failure to organize the information coming from different sensory modes is likely to lead to an impairment of the dynamic characteristics of manipulative skill owing to lack of integration of visual, tactile, and proprioceptive data.

Probably most important of all are the central mechanisms concerned with bringing past material to bear upon the present situation, for it is this process more than any other which seems to run consistently through every aspect of skill.

Two types of failure by these mechanisms appear to be possible:

(*a*) There may be failure to carry over from the past to the present, either because the appropriate learning has not taken place in the past or because there has been forgetting or because for some reason the past material required is temporarily 'unavailable', as, for instance, when we fail to recall something which at other times we can recall perfectly well. In such cases there may be a total breakdown of performance, or some alternative means of dealing with the material may be adopted which is more or less inadequate.

(*b*) There may be failure to exercise adequate *control* over the process of bringing past material to bear on the present situation. This would appear to lead to three important kinds of result:

(i) The incoming data may 'touch off' more than one pre-existing organization with the result that perception or action is confused. This type of failure is of interest in connexion with age, as it seems reasonable to suppose that a subject's repertoire of pre-existing organizations increases with age, and that the greater the number of these the greater will be the likelihood of confusion arising. The chance of such confusion is much increased by the fact that the pre-existing organizations appear frequently to be touched off not by the stimulus-situation as a whole, but by some detail of it which may attract attention but be of little relevance.

(ii) In a great many tasks, it is necessary not only that the correct actions should be performed, but also that they should be performed in the correct sequence. An important type of breakdown of skill occurs when the subject produces the correct actions but fails to order them in the correct temporal sequence.

(iii) It would seem that in the course of repetition the organizations concerned with the performance of a task become more complete and act with less reference to external stimuli, and that this may sometimes lead to a breakdown of skill. What seems to happen is that a sequence of actions 'runs itself off' with insufficient reference by the later members of the series to the effects of the earlier members. Essentially this is, of course, a failure of the feedback via the object manipulated which would normally keep the skilled performance and the object in close relation to one another. But it seems clear that it is often not so much a failure of the feedback to take place at all, as of a failure to use the data provided by it to control the pre-existing organization.

The location of any change of skill within the scheme outlined is unfortunately seldom easy. Any change of moderate degree which affects only one part of the chain of events from 'stimulus' to 'response' is likely to make little difference to overall achievement provided that the dynamic character of the skill remains unaffected, as this will enable compensation for any deficiency to be made. At the same time any gross failure in one part of the system is likely to affect all the others to some degree, so that when a substantial change of achievement does occur it may be difficult to ascertain whether it is due to some severe failure of one part of the mechanism, or to a more general impairment such as would, for instance, occur if there was any widespread physical deterioration in the brain.

Because of this, it seems clear that any attempt to study changes of skill not only must deal with overall achievement but must take into account the manner in which this achievement is attained, by making as thoroughgoing an analysis as possible of the performance, in order to assess separately the functioning of the different mechanisms involved.

In making such an assessment when skill deteriorates, it has to be recognized that we are usually looking for signs of a *partial impairment* because a total disability of any part of the mechanism would usually lead to such gross effects that it could be located without much difficulty. Partial impairment of the efficiency of any stage may show itself in one or more of four ways:

(i) Temporary breakdowns of function may occur to such an extent that obvious errors are made. These breakdowns may

be of several different kinds, e.g. they may be due to some event in the chain failing to occur at all, or to some inappropriate event occurring, or to an otherwise appropriate event occurring at the wrong time.

(ii) It would appear probable that a very common impairment is that the mechanism concerned becomes insensitive, requiring a greater input than usual to operate it, but operating more or less normally if this greater input is provided. It is probably insensitivity of this kind which is responsible for the finding —in a very significant experiment by Weston (1949)—that performance in a visual task declines more sharply with age in dim light than it does when the level of illumination is high.

This kind of insensitivity would seem to be shown also in cases when the subject requires more than the normal amount of information for the solution of a problem or the forming of a judgement, although the solution or judgement may be sound enough once the information required has been supplied.

(iii) It appears that impairment may frequently lead to a condition in which the various receptor mechanisms work satisfactorily in the sense that they do not cause errors, but work more slowly. It is not clear how far this type of impairment should be distinguished from that leading to insensitivity, as there exists a wide class of mechanisms, among which may be some of those in the brain, in which speed of operation rises with level of input, so that if input is kept constant impairment will show as a loss of speed, or if speed is kept constant impairment will show as the requirement of higher input.

(iv) More subtly but very interestingly, any reduction of data from external objects will, owing to the dynamic nature of skill, tend to increase the part played in shaping the performance by the schematized past experience brought by the subject to the situation. Any impairment of the early stages of the receptor side will, therefore, tend to produce relatively little change in a skill which has already been firmly established, but will make for a marked deterioration of performance at unfamiliar tasks. In the wider field of everyday behaviour, the same impairment would seem to be a reasonable explanation of the

tendency of some older people, especially those showing clinical senility, to display poor comprehension of the present situation combined with detailed remembering of past events.

Impairments of all these kinds appear fairly obvious in some people of extreme old age. Whether, however, the changes occurring in people during middle and early old age are to be regarded as essentially of the same kind but of lesser extent, is a matter for investigation.

SUMMARY REVIEW

We may summarize the view that we have put forward by looking at some of its salient features from a slightly different standpoint. If we could interrupt a skilled activity at a particular instant and examine closely what was taking place, we should find a detailed movement—let us say of the hand—in progress. This would, however, be a part of a more complex pattern of movement, this again a part of a cycle of performance of the task, and so on. The movement, the pattern of movements, the cycle of performance are all 'organizations' in the sense that we have used the term. It can thus fairly be said that there is in use, at any time in the performance of a skilled task, not one but a whole hierarchy of organizations. Some of these are concerned with the immediate details of what is being done at the moment; others are concerned with more general aspects of the task, integrating the details into larger units—in a sense *using* them.

Each of these organizations has its receptor and its effector aspects, each is capable of becoming firmer in the course of experience, and each is modified and 'kept in line' by what has been done previously.

Organizations high in the hierarchy appear to be high not only in the sense that they place the details of the performance in a larger setting, but also in the sense that they operate over a longer period of time, often extending far backwards and forwards from the instant under investigation.

The presence of a hierarchy of organizations all acting simultaneously makes it seldom, if ever, pertinent to talk about human behaviour as involving single stimulus-response chains, however complicated they may be conceived as being. Each action is the result of many stimulus-response chains welded together in such a way that the stimulus and response of one chain may be only a small sub-unit in some larger chain. In any task it is usually only one of

these chains which enters consciousness and is regarded as *the* stimulus-response unit of the particular task. But the others are nevertheless present, and a change of conditions under which the task is done, or long-continued exercise of the skill, may result in consciousness shifting to a different chain in the hierarchy. Thus, for instance, when fatigue sets in, the overall pattern of skill and the end to be achieved may be replaced in consciousness by the smaller details of the task. It seems probable that, in most tasks, performance will be most efficient and morale highest when consciousness is concentrated at a particular level in the hierarchy, the optimum level probably differing for different tasks and from one individual to another.

When breakdown of skill occurs, it may be general but is more likely to affect only one organization in the hierarchy directly. Within this organization it is likely to be located in only one aspect, such as the receptor or effector. A breakdown may be a total failure, or it may be partial in the sense that the organization can function efficiently but requires a greater 'input' or longer time. The effects of such breakdown, although in some cases localized, are likely to extend to other aspects of the same organization, and to other organizations in the hierarchy, which are dependent upon the parts which have broken down. Thus effector performance may fail because the necessary perceptual response is inadequate, even though the effector mechanisms are themselves in full working order. Similarly the details of a performance may become ineffective because they are not adequately unified into a sequence, although each is in itself unimpaired.

IMPLICATIONS FOR RESEARCH ON SKILL

From what has been said it will be seen that any experiment which studies only overall achievement without an analysis of how that achievement was attained, or which deals only with a single score such as time taken or number of errors made in carrying out a task, is only a very rough first approximation to the adequate study of a skilled performance. A full study requires a set of scores which analyse the performance into components, and which are used simultaneously to build up a picture not only of the results achieved but of the methods used. Similarly, in assessing a difference or change of skill, all the scores should be studied together and the pattern of similarities and differences in them used to locate the change and describe its nature.

When making such a study it is important to bear in mind that total

achievement is often by no means the same thing as the generally accepted criterion of performance. In many cases this criterion has the status of a score dealing with only one part or aspect of the performance. For instance in dart-throwing and many similar aiming tasks, the score obtained on the target is a matter only of accuracy of throwing and takes no account of the time taken in aiming or the way in which the aiming was carried out. A full study of performance at such a task requires, as a measure of total achievement, some integration of accuracy with time taken. For analysis, accuracy needs to be broken down into, perhaps, vertical and horizontal components, and it may be necessary to study the relationship of each throw to the next, i.e. to obtain scores which indicate the nature of corrections made for errors. The total time similarly may need to be split up to indicate how it was spent, e.g. how much was spent taking aim and how much was spent observing the results of each throw.

The measurements that are required for an adequate study of a skilled performance will obviously vary with its nature, but it would seem that generally it is desirable to take two sets of measurements thus:

1. A record of *events* such as 'successes' and 'errors' together with information about the nature and extent of the errors and their relationship to other events.
2. A detailed record of the timing of the various events.

Careful control of the objective situation presented to the subject and of any characteristics of the subject, such as degree of previous training, must obviously be made, but these are matters general to all psychological experiments.

Such requirements set a high standard of technique, and the need to study times is liable to involve elaborate apparatus. The accuracy required, and the need to record continuously, preclude the use of stop-watches and chronoscopes. Even pens recording on a moving paper strip, which we have used in our experiments, involve heavy labour in scoring records. In our work reported here we have accepted this and have made adequate measurement wherever we could. But it must be understood that the principles we have enunciated are in part the result of our experience in this work, and that in consequence some of our experiments fall short of what we now see to be desirable.

IV

SUBJECTS TAKING PART IN THE EXPERIMENTS

In common with almost all previous workers in the field of ageing we have encountered severe difficulty in obtaining suitable subjects. It is comparatively easy to obtain men in their twenties, but from the age of 30 onwards the task becomes increasingly difficult.

Broadly speaking, two difficulties are involved:

1. Men over the age of 30 are often very unwilling to submit to testing.
2. It is not at all easy to be sure that groups, especially small groups, of subjects drawn from different age-ranges are really comparable for the purposes of our investigations.

1. *Unwillingness to submit to testing*

This is a finding of considerable interest in itself, and one which merits further study. When asked to come and act as subjects, men over 30 commonly plead lack of time or raise difficulties such as that they are unable to get to the laboratory. To a considerable extent these pleas are, of course, justified; but it is quite clear that in most cases they are being used as excuses, and that the real reason for unwillingness is fear of being tested, in particular if the word 'psychology' is mentioned. Here we have clear evidence of the influence of a popular belief about the nature of psychological experiments, which presumably stems from the fact that in most people's minds 'psychology' is synonymous with 'psycho-analysis'. In view of this difficulty we have endeavoured scrupulously to avoid using the word 'psychology' when persuading subjects to come and be tested. It is partly for this reason that we have on several occasions taken our experiments out of the laboratory to other centres.

The fear of being tested seems to be a fear of doing badly and appearing foolish. It seems that subjects know well the popular opinion that as one advances through middle age one's ability falls off, and that they are very unwilling to have this fact demonstrated upon themselves. This fear manifests itself in several ways:

(i) Typical remarks made by older subjects (i.e. those over 30) before being tested were:

'You don't really want me, do you? I shan't be very good.'
'You can't expect too much of me; after all, I'm nearly sixty.'
'So this is where you make a fool of me, is it?'

(ii) After being tested, older subjects almost always inquired 'how they had done' and demanded to know how their results compared with the average, with those of younger subjects, and with those of any friends known to have been tested previously. Subjects were always told that scores were treated as strictly confidential, but this did not prevent reiterated attempts to obtain information about friends in several cases. This strong interest in the relationship of one's own performance to those of others was very seldom manifested in subjects under 30, although this must not be taken to imply that it was entirely absent.

(iii) Visible relief and pleasure were shown by older subjects upon being told that they had 'done well' or 'had scored better than many of the younger subjects tested'.

(iv) Even when told that they had done well, many older subjects showed a strong tendency to criticize their performances and to produce reasons such as eyestrain, tiredness, preoccupation with other problems, and so forth, for not having done better. It should be noted that the actual performances frequently did not merit this self-criticism.

These findings are of particular interest in view of the theory which has often been put forward that the fall in performance with increasing age is due to 'lack of motivation'. The term itself is ambiguous and seems to be used variously to denote:

(*a*) Unwillingness on the part of subjects to put forth their best efforts at doing psychological experiments at all.

(*b*) Lack of interest in the actual tasks set by the experiments.

From what has already been said it seems clear that our subjects certainly did *not* approach the experiments in any spirit of not intending to put forth their best efforts. In this respect they were certainly as well motivated as the younger subjects. Indeed, it seems possible that in some respects they may have been hampered in their performance not by under-motivation but by over-motivation leading to anxiety and 'disorganization'.

Our results contain hints, however, that older subjects may find some laboratory tasks less interesting than younger subjects do, with the result that they are unwilling to sustain their initial effort. In the experiments we have done so far, we have endeavoured to minimize the influence of this factor by making the tasks as inherently interesting and worth-while as possible, and it is clear that in most cases this aim has been achieved. We are, however, noting carefully instances of lack of interest with a view to more direct investigation later of the conditions under which interest is and is not maintained.

2. *Matching of different age-groups*

Most of our subjects under 30 have been either students or naval ratings taking part in Service experiments in Cambridge. Subjects over 30 have been obtained from six main sources:

(*a*) Friends and acquaintances of members of the Unit.

(*b*) Groups recruited by a relative of one of the members from among friends, tradesmen, and other acquaintances in and around his home village in Sussex.

(*c*) Army officers and other ranks obtained through the Cambridgeshire and Isle of Ely Territorial Army Association.

(*d*) Polish army personnel and agricultural workers obtained from two Polish Resettlement Corps camps and two County Agricultural Executive Committees' Polish Hostels.

(*e*) Members of University and Local Education Authority adult classes and adult clubs in various centres.

(*f*) Members of old people's clubs in Cambridge.

The difficulties encountered in obtaining older subjects, and the small size of the groups tested as a consequence of this, raise the question of whether the groups used were sufficiently comparable in respects other than age for any valid conclusions, even of the most tentative kind, to be drawn. We believe, however, that the equating of our different age-groups has been fairly adequate. In particular:

(i) Older and younger subjects were chosen to ensure that, so far as possible, the older subjects were of a status, &c., corresponding to that which the younger subjects might be expected to possess when they reached the same age. Thus, undergraduates were balanced by university teachers, business men,

professional men, and army officers, either actually engaged in the work of their business or profession or, in the case of some more senior subjects, retired. Naval ratings were balanced by others of a grade of occupation comparable with that which the ratings had occupied before call-up or which they expected to occupy on demobilization, due regard being paid to the normal likelihood of promotion with age.

The need for careful control of occupational and other status was brought home to us during one of our early experiments in which an apparent age-difference turned out to have been due to the inclusion of a large number of servicemen in the youngest age-range (Szafran and Welford 1949). In treating the results of the experiments reported here, we have been at pains to minimize falsification of this nature. It seems clear, however, that occupational and other environmental influences associated with age may influence performance in ways which are difficult to detect and harder to control, and that until more is known about them some caution must be exercised in interpreting the results of work such as ours. It may be remarked in this connexion that studies which follow individuals over a long period of years are just as, if not more, subject to this kind of distortion than are those which, like ours, take samples of different age-ranges in the present-day population.

(ii) The unwillingness of older people to submit to testing confronts an experimenter with a choice between taking as subjects a highly selected and unrepresentative group of volunteers who for one reason or another show less of this unwillingness than their contemporaries, or persuading unwilling subjects to act with the consequence that many will be working under an emotional strain. We have in general chosen the latter course, and tried to make sure that every potential subject who was approached was eventually persuaded to act, but we attempted to minimize any disturbing effects of nervousness by using every endeavour to put subjects thoroughly at their ease.

(iii) Some bias in initial selection of persons to be approached doubtless occurred. For instance, higher-grade older subjects were for various reasons somewhat easier to obtain than lower. Such bias is, however, unlikely to invalidate results in

the sense of artificially increasing differences between age-groups. It is more likely to decrease these differences—a tendency which, though undesirable, is less serious than its opposite.

The difficulty of obtaining suitable subjects has undoubtedly been the limiting factor in our experimental work. Each experiment requires some fifty or more men or women of varying ages whose backgrounds are such that the older might reasonably be the elder relatives of the younger. Of these it is desirable that some should be taking part in an experiment of this nature for the first time, and that others should have come to us before. The former increase the generality of any findings which are common to several experiments, the latter provide a deeper understanding of the interdependence of capabilities, and the changes of these with age, within individuals.

V

EXPERIMENTAL RESULTS

I. PRELIMINARY REMARKS, AND EXPERIMENTS ON MANIPULATORY SKILLS

THE difficulty of getting samples of different age-ranges which could be regarded as comparable presented a choice between two methods of conducting experiments. We could on the one hand have overcome the difficulty of the high degree of variation between individuals, and perhaps also of such influences as occupation, by taking large samples and concentrating all our efforts on one or two studies. On the other hand it seemed possible that by dividing our available subjects between several smaller-scale experiments, each presenting a different task, we might obtain results which, although not conclusive for any one experiment alone, would add up over the whole series to findings of greater generality and reliability. This accordingly was the course we adopted, and we feel sure that by doing so we have been able to get farther in the time than we otherwise should have done.

In selecting experiments for presentation we have been faced with a choice of either laying before the reader the fullest information we have available at the present time, or indicating only those results about which we feel reasonable confidence and for which an overall interpretation can be attempted. In choosing the latter course we wish to make it clear that we are not, so far as we can ascertain, omitting any information which runs counter to the views we have expressed. The experiments we have chosen hang together as a set which appears to illustrate an important type of change which occurs with age. We expect to be able to present further sets of experiments which deal with other types of change at a later date.

In several of the experiments we have had some difficulty in presenting the results clearly and so as to give a fair picture of the performances of the different age-ranges. The nature of the tasks studied has been such that the measures taken are often essentially and necessarily complex. We have been mindful of the trouble this may cause to the reader, but have felt it better to deal with the results in their proper complexity rather than attempt a false clarity by oversimplification.

Our procedure when working out the results has always been to

examine the individual scores in the form of scatter-diagrams. These have usually revealed some differences between age-ranges which are clear enough, but the distributions are often non-normal (this is to be expected with some of the scores used) and the variation between individuals is often high. In particular the older age-ranges show a tendency to produce occasional exceptional individuals whose performances are strikingly better than those of both their contemporaries and their juniors. Inspection of the scatter-diagrams and the comparison of various measures have, however, convinced us that in most cases the arithmetic or geometric means give the fairest picture of the trends between age-ranges.

We have in all cases where appropriate carried out statistical tests to assess the significance of our results. In the text we have, however, attempted to keep the statistics severely in the background. Our rule has been that when one measure is said to be different from another the difference between the two has, unless otherwise stated, been tested and found significant at the 5 per cent. level or better. For the benefit of those who wish to examine the evidence more closely, the actual statistics concerned in each comparison are set out in the Appendix.

Experiment 1

GRID-POSITION MATCHING EXPERIMENT

In this experiment the subject was confronted by an apparatus* on which was a plate carrying two pieces of graph-paper approximately 6 × 4 inches. The subject's task was to move, by means of a handle, a pointer with a spot on it so as to make the position of the spot on the right-hand piece of graph-paper similar to that of a small steel ball about $\frac{1}{16}$ inch in diameter on the left-hand piece, relative to vertical and horizontal co-ordinates on the two pieces. The layout of the grids and pointer is shown diagrammatically in Fig. 1.1.

When the subject thought the pointer was in the correct position he pushed a small button mounted on the handle. If his judgement was correct, the ball started to move about the left-hand grid. If it was incorrect, nothing happened.

* The apparatus for this experiment was originally designed by Professor Sir Frederic Bartlett and was modified after some preliminary experiments to provide a detailed analysis of the task.

The subject went on making attempts until he was successful in making the ball move. He was instructed that as soon as this happened he was to press a key at the side of the apparatus which stopped the ball in a new position on the left-hand grid, and was then to start the cycle of operations over again.

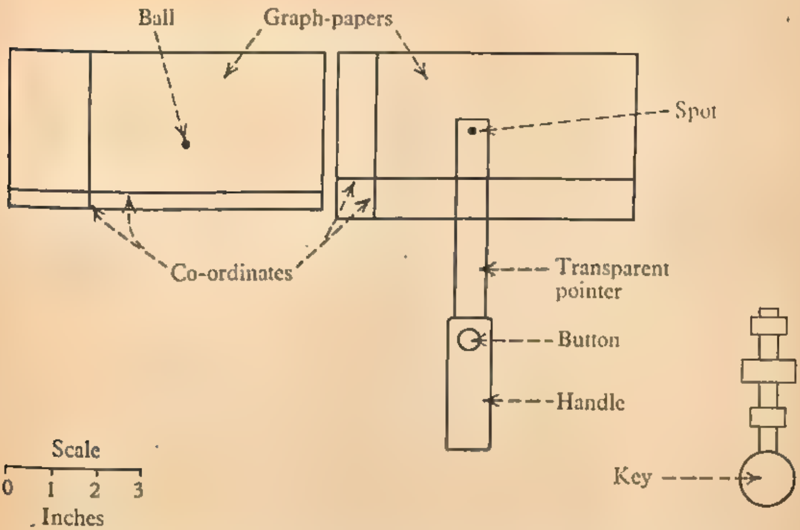

FIG. 1.1. Grid-matching apparatus. Diagram of display and controls

It will be seen that the subject was set a fairly complex skilled task. The nature of this task was such that the subject had to make the same *achievement* each cycle of operations, i.e. causing the ball to move and stopping it again. The pattern of hand-movements required was, however, different for each cycle so that the task did not involve the building up of any strictly stereotyped succession of movements. At the same time the task was sequential in the sense that the completion of each part of the cycle set the stage for performance of the next.

Each attempt to start the ball and each pressing of the key to stop it in a new position was recorded on a paper strip moving over a constant-speed drum. For purposes of this recording the attempts were divided into three classes:

(*a*) Successful attempts in which the ball was actually made to move.

(*b*) Small errors, i.e. unsuccessful attempts in which the amount of error was less than ½ inch.

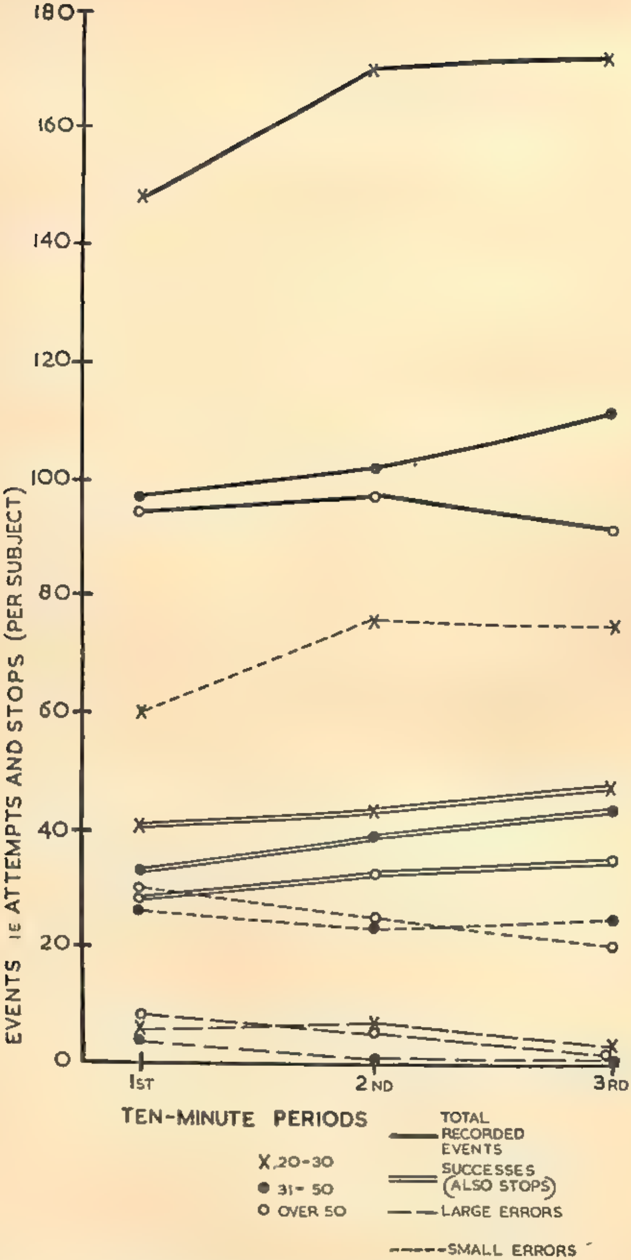

FIG. 1.2. Analysis of recorded events

The subjects in their twenties recorded substantially more events than those over 30. Most of these additional events were, however, small errors.

(c) Large errors, i.e. unsuccessful attempts in which the amount of error was over ½ inch.

The subjects were divided into three age-ranges as follows:

(a) Twenty-three naval ratings, R.A.F. aircrew, and friends and acquaintances (mostly students) of the members of the Cambridge Laboratory, with ages ranging from 18 to 29.

(b) Eleven subjects with ages ranging from 30 to 44. These were either friends and acquaintances of members of the Laboratory or members of a group collected from a town and village in Sussex by a relative of the author.

(c) Seventeen subjects with ages ranging from 45 to 82, obtained in the same manner as (b).

The subjects were instructed in the operation of the pointer, and told that their task was to make the ball move by aligning the pointer correctly, and that *as soon as* the ball moved they were to stop it and try again. Each subject was given a few practice 'runs' to get the 'feel' of the machine and upon pronouncing himself satisfied that he understood what to do was given half an hour's continuous work.

Results

From the paper record it was possible to work out a large number of different scores of relevance according to the interest with which the data is approached. One set of scores is shown in Fig. 1.2, and another in Figs. 1.3 and 1.4. Fig. 1.2 sets out the *total numbers of recorded events* together with an analysis of these into components, namely

'successes',
attempts with large error,
attempts with small error, and
'stops' (the figures for which are obviously the same as for 'successes').

The abscissa is divided into three 10-minute periods in order to show the results in greater detail.

It will be seen from Fig. 1.2 that the number of events recorded for the subjects under 30 was very much greater—about 65 per cent.—than for the two higher age-ranges. Most of this increase was due to the markedly greater number of small errors, the subjects under 30 making about three times as many as the others. Compared with this, the differences between age-ranges in the numbers of successes were

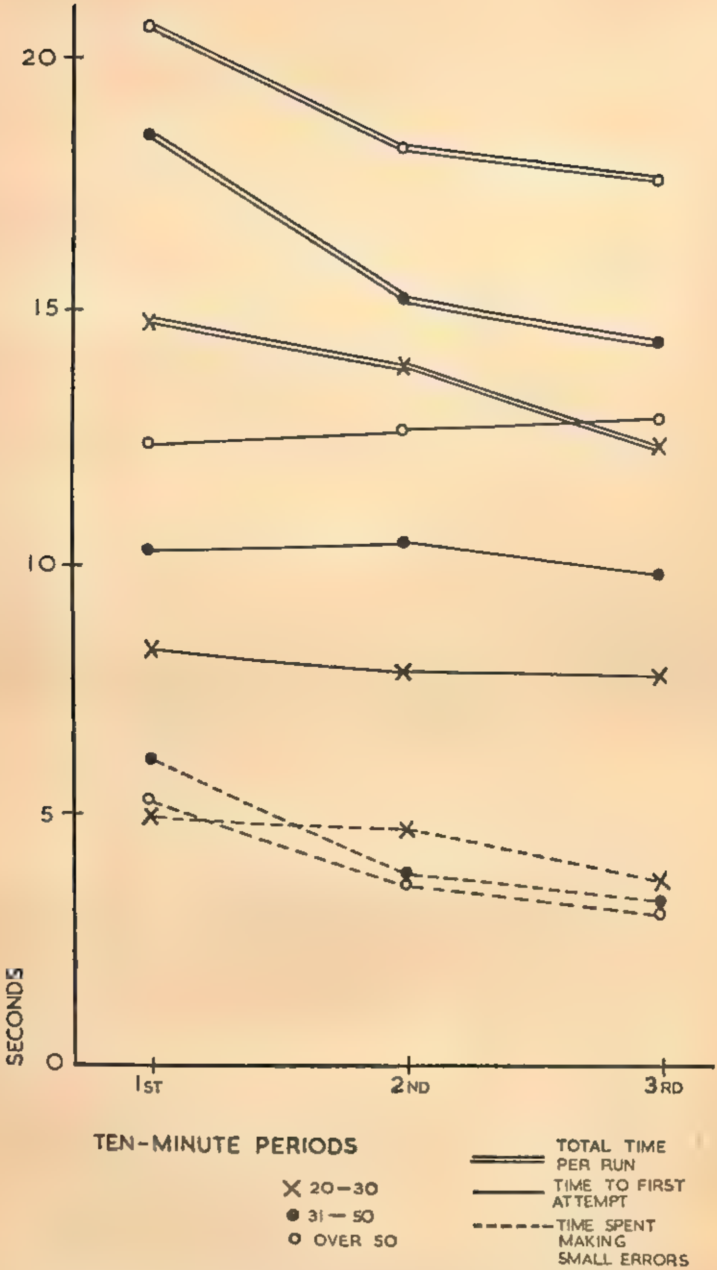

FIG. 1.3. Analysis of time per 'run' (large components)

Most of the increase with age in total time per run was due to the increase in 'time to first attempt'.

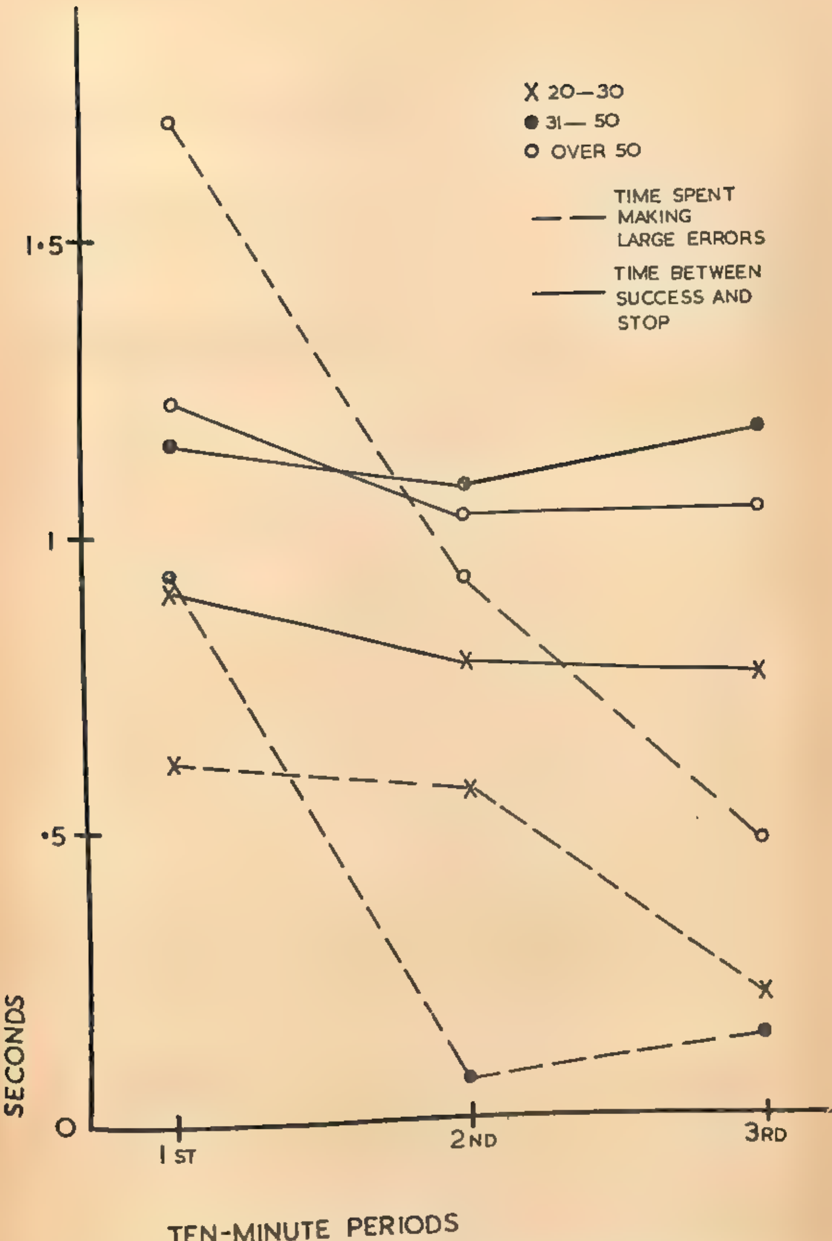

FIG. 1.4. Analysis of time per 'run' (small components)

The rise with age in the time spent making large errors, which was striking during the first ten minutes, became less well defined during the second and third.

small. The under-30 range made about 15 per cent. more than the 30–45 range and about 36 per cent. more than the 45–82 range, but individual variation was great so that the differences are not significant except in the last 10 minutes.

In Figs. 1.3 and 1.4 are set out an analysis of the average times per run for the three age-ranges. In Fig. 1.3 are given the total times per run and their principal components, namely:

(i) the time elapsing between stopping the ball at the end of one run and making the *first attempt*, whether successful or unsuccessful, to start it again, and

(ii) the time spent making small errors.

Fig. 1.4 shows with a larger-scale ordinate the minor components:

(iii) the time spent making large errors, and

(iv) the time elapsing between starting the ball and stopping it again in readiness for the next attempt.

The 'total times per run' are, of course, essentially the same scores as the numbers of 'successes' in Fig. 1.2. It will be seen that the 30–45 age-range took, on the average, about 15 per cent. longer than the under-thirties, and that the over-forty-fives took about 18 per cent. longer still. As remarked before, the differences are not, however, significant, except during the last 10 minutes.

The component which contributed most to these increases was clearly the 'time to first attempt', although a smaller but significant contribution was made by the 'times from success to stop' and, during the first and second 10-minute periods, by the time spent on large errors. The times spent on small errors show little change with age—indeed the two older age-ranges spent a little less time on these than did the youngest.

Summarizing the information from Figs. 1.2, 1.3, and 1.4, it appears that the older subjects' performances tended to be slower and more deliberate than those of the younger, but substantially more accurate.

Discussion of the results

The main interest of these results would seem to lie in the increase with age of the 'time to first attempt' or in other words the time taken to make the initial adjustment of the pointer to each new position of the ball on the grid. Of possible reasons for this we may dismiss three with fair certainty:

1. *Inability to see the grids clearly.* It is true that the lines on the graph-paper, $\frac{1}{10}$ inch apart, imposed a fairly fine visual task, and that several of the older subjects complained of eyestrain when they had been doing the task for some minutes. Poor eyesight does not, however, seem sufficient, at any rate as a direct explanation of the slowness of performance on the part of the older subjects, because:

(i) There was never any suggestion that the older subjects could not see the grids clearly. One subject in the sixties who did have this difficulty was excluded for this reason. All subjects who normally wore spectacles for close work wore them during the experiment.

(ii) Complaints of eyestrain did not seem to correlate in any way with poor performances.

(iii) If indeed visual acuity had been grossly impaired among the older subjects, we might have expected them to make a very much larger number of small errors than the younger subjects. This, as can be seen from Fig. 1.2, is the reverse of what occurred.

2. *Lack of interest.* As mentioned in Chapter IV, older subjects often expressed some unwillingness to submit to testing. Those taking part in the present experiment were no exception. This fact did not, however, lead to any lack of *willingness to put forward their best efforts.* It was quite clear from remarks made by the subjects both when they had been introduced to the experiment and given their instructions, and when they had completed the experimental session, that they had been very ready to do their best and that they found the task interesting and fascinating. As further evidence of the interest taken in the task it may be mentioned:

(i) The subjects were not told beforehand how long they would have to work, but after they had completed the half-hour session they were asked to estimate the time they had been doing the task. Almost without exception they substantially underestimated the time, usually assessing it at about half its actual length.

(ii) When, some twelve months after the readings were taken, the subjects over 30 were approached again to take part in further experiments by the Unit, all except two enthusiastically agreed to do so, many explicitly stating that they had enjoyed the task and would like to take part in more of the same kind.

3. *Deficiency in the effector mechanism* seems to be inadequate to account for the present results because:

(i) The movement of the lever was sufficiently stiff to damp out the effects of any but the grossest shakiness of hand.

(ii) The time required to execute the actual movements of the lever, as opposed to recognizing the correct position in which to place it, was comparatively short. We were unfortunately not able to take timed records of the actual movements made by the subjects when operating the lever, but observations during performance showed clearly that the extra time taken by the older subjects was not used in the actual moving of the lever, but in checking its position after movement before pressing the button in the attempt to start the ball. In this respect, the younger and older subjects displayed a profound difference of method. Younger subjects tended to swing the pointer into position with a kind of sweeping motion, stop it, and press the button, all more or less in a single movement, seeming to look at the graph-papers as a kind of 'general setting' within which they located the ball and pointer immediately. The subjects over 30 tended to look carefully and in detail at the graph-paper, move the pointer into position, and check the accuracy of this position by looking rapidly back and forth from one grid to the other, often several times, sometimes counting the squares on the paper, before they pressed the button.

The smaller number of errors made by the subjects over 30 and the observations of their typical method of work seem to leave no doubt that by far the most important cause of their longer time between stopping the ball at the end of one run and making the first attempt to re-start it was an *increased carefulness* in positioning the pointer.

In attempting to assign a reason for this greater care two types of possibility must be borne in mind:

(i) That older subjects brought to the task some tendency to caution which had been built up in the course of experience over a number of years into a general mode of approach to certain types of task, and which was applied because it was considered superior to other modes—i.e. carefulness was a modification of behaviour that comes with age as a result of 'rewards' and 'punishments' in the past.

(ii) That the extra carefulness on the part of the older subjects was in the nature of a compensatory reaction adopted in the face of some disability which increases with age and made the task difficult to attack by the methods usually adopted by younger subjects.

Although the present data do not provide the means of choosing definitely between these two possibilities, it may be remarked that had the careful method of work been adopted by the older subjects as being superior to that adopted by the younger in any absolute sense, we might have expected that the performance would have been more accurate *in all respects*. This did not, however, appear to be so. Although the subjects over 30 were strikingly more accurate than those under 30 as regards the number of *small* errors they made, the subjects in both the higher age-ranges took considerably *longer* making *large* errors during the first 10 minutes.

These large errors were the result of the fact that the co-ordinate lines were placed in a different relation to the edges of the two grids (see Fig. 1.1, page 35) so that a subject who attempted to position the pointer by reference to the edges instead of to the co-ordinate lines placed it in an incorrect inch-square of the right-hand grid. The misalignment of the grids was purposely introduced as a confusing feature of the display, and, from both the longer time taken by the older subjects to recognize and adjust to it and the remarks they made in doing so, it appeared that its confusing quality affected them more than it did the younger. Once the misalignment had been recognized, however, it ceased to trouble them to any great extent. As evidence of this, it may be seen from Fig. 1.4 that during the second and third 10 minutes of the experiment the time spent on large errors by the subjects in the 30–45 age-range dropped to practically nothing, and that, although those in the over-45 range continued to spend more time on large errors than did the rest, it had dropped to a low level by the third 10 minutes.

The longer time spent on large errors during the first 10 minutes cannot reasonably be regarded as due to any defects of vision or of effector mechanism, but appears to have resulted from some deterioration in the older subjects' power to comprehend the essential static features of the display. If this is so, it raises an interesting possibility with regard to the longer time taken by the older subjects between stopping the ball at the end of one run and making their first attempt to restart it. It is that, just as older subjects took longer to comprehend

the features of the display which remained the same throughout the experiment, so they also took longer to comprehend each change introduced into the display by change in the position of the ball between runs, and that the carefulness shown in their performance was a compensatory reaction to this increased difficulty. The evidence from the present experiment is, of course, quite insufficient alone to support such a view, but it may be noted in anticipation of what is to be said later that this view accords well with the evidence from some of our other experiments.

Before passing to these, we may mention two other interesting findings in the present experiment.

1. It was seen in Fig. 1.3 that the subjects over 30 took longer to stop the ball after it had been started. Although at first sight this looks like one more aspect of slowness, observations of the subjects provided what is at least a partial alternative explanation. The instructions were that the ball should be stopped *as soon as* it was started. It was clear, however, that many of the subjects over 30 were contravening the instructions to the extent of waiting until the ball was near the co-ordinate lines before stopping it. This action, of waiting until the ball was in an easy position before stopping it, appeared to be an interesting case of *planning* the work as a whole, i.e. the subjects were willing to take longer over one part of the task in order to save time and trouble over a subsequent part. The fact that this contravention of instructions appeared frequently among the subjects over 30 and hardly ever among those under 30 suggests that this tendency to planning may increase with age.

2. It must be emphasized that, although the results we have outlined above represent the trends of the groups we have tested, there were some individuals who departed markedly from the general run. The most striking of these was a man in his late fifties, whose results have been excluded from Figs. 1.2–1.4 because they are so much at variance with those of his contemporaries that their inclusion gave a somewhat distorted picture of the central tendencies in the highest age-range. In justification of this procedure it must be said at once that the inclusion of his results does not affect the means to an extent which invalidates any of the statements we have made, nor does it render any of the significant results insignificant or vice versa, except that the total time per run (or number of runs per period) ceases to differ significantly with age in any of the three 10-minute periods. The

magnitudes and significance levels of the components of these totals remain very little affected.

The subject concerned attained 342 successes during the half-hour, which was

- about 40 per cent. higher than the highest performers in the 30–45 and under-30 age-ranges;
- well over twice that of his nearest contemporary;
- nearly four times the mean of the rest of the over-45 range;
- over $2\frac{1}{2}$ times the mean of the under-30 range.

His method of work was quite different from that typical of his contemporaries. Instead of a careful positioning of the pointer before making an attempt to start the ball, he swung it rapidly into position and pressed the button immediately. If the ball did not start, he proceeded to make several rapid attempts within a small circle round the point at which he had made his first attempt. Had we been able to test very large groups of subjects we should probably have found that he was on the tail of a continuous distribution. Whether or not this is so, his result serves to raise the interesting problem of how far the changes associated with increasing age are likely, while lowering the average standard of performance, to produce a few exceptionally able individuals. With regard to this problem two points may be mentioned. First, that we have found exceptional performers in our higher age-ranges in several of our experiments, and second, that the exceptional performance by this subject seemed to be fairly specific to a particular type of task. The subject concerned performed in several other experiments afterwards and in only one other (the tracing task of Experiment 4) did he show a similar striking achievement.

The last point is in line with what would be expected if the changes accompanying age are to be thought of as due to a restriction of the range of things which can be done. Performance at any task is the resultant of the interaction of what the subject brings to the task and the demands of the task itself. It will attain a high standard when, and only when, the 'fit' between these two is good. If the range of what the subject brings diminishes with age, the *likelihood* of an older subject attaining a high standard at any task will be reduced, but the ability to do so at *some* will remain, and may indeed increase.

In concluding our account of this experiment it seems relevant to ask, whatever theoretical interpretation we place upon it, whether it

was the younger or the older subjects who, from the practical standpoint, showed the better average performance. Such a question is by no means easy to answer, and depends very much on what we regard as the criterion of 'goodness'. If we are interested in the number of times the ball is made to move in a given period of time, i.e. in the total amount achieved regardless of any other considerations, then the younger subjects must be regarded as better, although they are not very markedly so. However, the older subjects achieved their results with much less effort wasted on small errors, so that their performance can at least be said to have been more *efficient*. Finally, if we are interested in accuracy, as we should be if every error represented waste of valuable industrial material, we must regard the older subjects as, on the average, clearly superior.

Experiments 2 and 3

THROWING AT A TARGET*

A criticism levelled against some previous work on ageing has been that the tasks given have been of a kind likely to be more familiar or more interesting to young subjects than to older. For instance, it has been suggested that some test materials of the paper-and-pencil type are similar to tasks given in school, and that older subjects are not only out of practice with this kind of task but have a feeling that they have left it behind them.

There are two ways of controlling the experimental task to avoid these criticisms: first, by presenting a task which is new to young and old alike; second, by presenting a task which is thoroughly familiar to all ages, in both cases taking care that it is one which the subjects can regard as worth while. In the grid-matching experiment the task was new to all our subjects and we were fortunate in finding that they regarded it as interesting. In the experiment to be described we attempted to provide a task which would be interesting and, at least in its simplest form, familiar to subjects of all ages. A further requirement was that, although it should involve some kind of motor performance and should be capable of yielding a detailed record of what was done, it should be substantially different from the grid-matching task.

* The account of these two experiments is partly based on Nuffield Research Unit into Problems of Ageing *Reports Nos. 3 and 4* by J. Szafran, both dated June 1948.

Bearing these requirements in mind we chose *throwing at a target* as being similar in nature to many fairground side-shows and a task which had the advantage, from an experimenter's point of view, that it could be varied in difficulty while remaining recognizably the same in other essential respects.

We had some difficulty in designing the target, and the objects to be thrown, in such a way that the latter would fall 'dead' and not slide about after they had landed, which would have made exact scoring impossible. After some preliminary experiments we chose loops of light chain 3 inches long as missiles, and constructed a target from strips of fibre-board intersecting in 'egg-box' fashion to form 49 (7×7) 3-inch-square open-topped boxes. The edges of the centre box were painted white to act as the 'bull'. The boxes were constructed so as to slant forward at a little over 45°. This enabled the subjects to see into the boxes when the target was placed flat on the floor, observe where each chain fell, and so obtain knowledge of the results of each throw as a guide to the correction to be made in succeeding throws. The fifty chains were fitted with small numbered ivorine tags and hung in order round the edge of a circular stand placed at a convenient height near the subject's dominant hand. The subjects were instructed to pick the chains off the stand one by one in order, and to throw them at the target, aiming for the 'bull' and taking their own time. While they were throwing, the experimenter slowly turned the stand so as to bring the chains into a position from which the subjects could pick them up easily.

Each subject was given the task under three different conditions:

A. In this, the simplest condition, the subject threw directly at the target over a distance of 8 feet. The task was thus one which on the receptor side presented a straightforward static display, which was modified in the course of performance only by the addition of the chains as the subject threw them. On the effector side it required an action which, while involving highly complex timing and co-ordination of muscles and posture, was familiar and did not require any great muscular effort. The required performance was from the receptor point of view simpler than that of the grid-matching experiment. From the effector point of view it was probably as complex or more so, with the important modifications, however, that the subject was not constrained to achieve a high degree of accuracy at each stage of the work before passing to the next, and that the movements required were more nearly repetitive.

B. The visual display was essentially the same as in condition A, but the motor performance was complicated by requiring the subjects to throw over a horizontal bar set 32 inches from the ground and 5½ feet away.

C. Both the visual display and the motor performance were complicated by requiring the subjects to throw over a screen of the same height and at the same distance as the bar in condition B. The screen hid the target from view, so that it could be seen only in a mirror placed behind it. In this condition the target was turned round so that the subject could still see into the boxes and obtain knowledge of the results of his throwing by looking in the mirror. The effect of this arrangement was to present the subject with the same motor task as condition B, but to require him to perform it in relation to a display which had its 'far-near' dimension reversed, and which was seen at a place other than that to which he had to direct his aim.

The 84 subjects who took part in this experiment were all from Polish Resettlement Corps camps and hostels in Cambridgeshire, and they probably formed a more uniform group in respects other than age than is obtainable from most other sources. They were divided into age-ranges as follows: 12 from fifteen to nineteen, 12 in the twenties, 24 in the thirties, 18 in the forties, and 18 in the fifties.

Each subject threw 50 chains in each of the three conditions at a single session. Between each group of 50 chains there was a short break in which the experimenter noted the time taken to throw and the positions where the chains had fallen, and at the end of the session the experimenter (who was himself a Pole) discussed the task with the subject and noted down any comments and introspections. To balance practice-effects, the three conditions were presented in different orders to different subjects within each age-range, and it is for this reason that the number in each range is a multiple of 6—the number of possible orders of presentation.

Methods of scoring

The scores used in examining the results may be divided into three classes:

1. *The mean distances in inches that the chains fell from the 'bull'.* When computing these distances, inaccuracy due to chains falling to the left or the right of the 'bull' was separated from that due to their falling too far or too near. This was done because the aspects of the action of throwing which lead to these two kinds of inaccuracy appear

to be different. Left-right inaccuracy is essentially, in most cases, an error of direction of throw, while far-near inaccuracy is an error of 'elevation', strength of throw, or time of releasing grip on the chain, or some combination of these. The separation seems to have been objectively justified by the results because the scores for inaccuracy on the two dimensions appear to have behaved somewhat differently.

2. *The times taken to throw.* Totals for 50 chains were measured by stop-watch.

3. *Types of inaccuracy.* The construction of the target as a series of boxes and the numbering of the chains had the important advantage that a record could be kept of the chains falling into each box. By comparing the position in which each chain fell with the position of the one thrown previously, indication could be obtained of the corrections made for errors. Examination of these differences showed that they varied in both extent and effect. Apart from those which left no residual error and those in which the second chain fell farther from the 'bull' than did the first, they divided naturally into two classes:

(*a*) *under-corrections*, when the second of the two chains being compared fell nearer the 'bull' than the first but still on the same side of it, and

(*b*) *over-corrections*, when the second chain fell on the opposite side of the 'bull' to the first.

These two types of correction were made the basis of an analysis of the *sources of inaccuracy*, the residual inaccuracies resulting from each type being tabulated as percentages of the total inaccuracy scores.

Results

In *direct throwing* (condition A), the results set out in Fig. 2.1 and Table 2.1 indicate no evidence for any deterioration of performance with age, as regards either accuracy or time taken. Indeed, what trends there were indicate a general tendency for performance to have been *more* accurate in the higher age-ranges than in the lower, although this rise of accuracy with age was small and not significant. It would appear, therefore, that in this task (in which the display was simple and static and the motor performance, although highly complex, was repetitive and relatively easy in the sense of not being rigidly constrained to a particular pattern) the subjects in the higher age-ranges did at least as well as those in the lower. Not only did the *achievement* represented by the scores for time and inaccuracy show

no appreciable difference with age, but the *method of attaining it*, as evidenced by the scores set out in Table 2.2 for type of correction, also showed no consistent change.

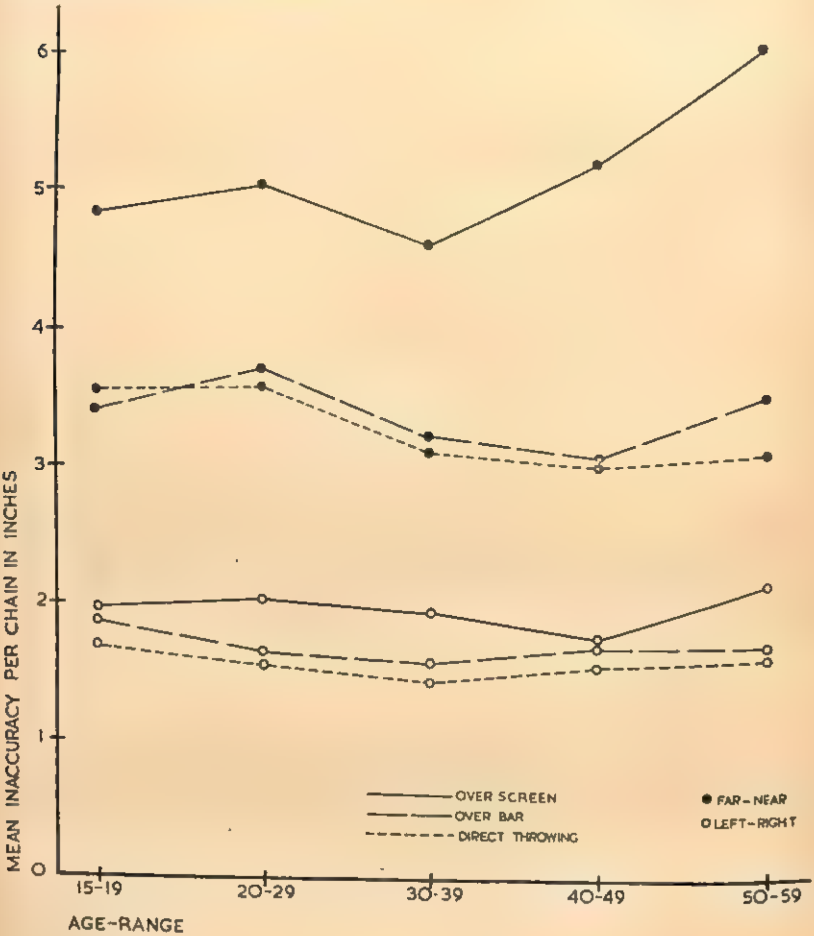

FIG. 2.1. Mean inaccuracy of throwing

The only substantial rise of inaccuracy with age was on the far-near dimension when throwing over the screen.

TABLE 2.1. *Mean times in seconds per subject to throw 50 chains*

Age-range	*15–19*	*20–9*	*30–9*	*40–9*	*50–9*
Direct throwing (condition A) .	156	140	153	143	147
Throwing over bar (condition B) .	155	142	153	148	149
Throwing over screen (condition C)	154	151	165	159	169

Similar results for direct throwing had been obtained in an earlier experiment by Miss Gillian C. Webb with subjects ranging from the 'teens to the seventies. The findings of this earlier experiment are interesting because most of the subjects were the same as those who took part in the grid-matching experiment, in which substantial changes with age were observed.

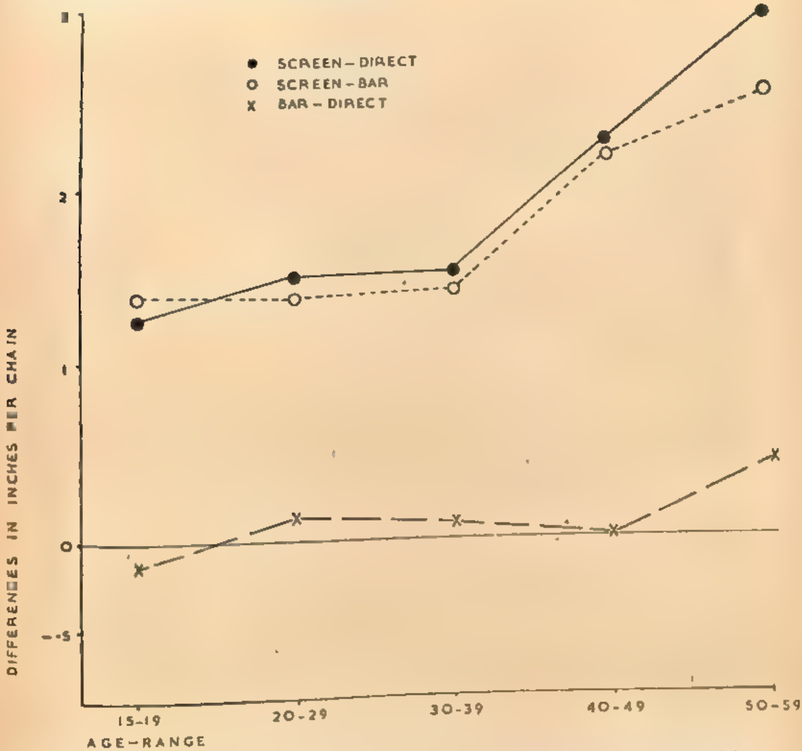

FIG. 2.2. Differences of far-near inaccuracy between the three conditions The differences between the bar and direct conditions were small and irregular. Those between the screen and bar conditions were larger and rose in the forties and fifties.

The results obtained for *throwing over the bar* (condition B) showed a striking similarity to the direct throwing as regards both accuracy and time. We may regard the differences between the inaccuracies and the times attained by the various age-ranges at direct throwing and those attained when throwing over the bar as a measure of the effect of the bar. These differences are set out in Figs. 2.2 and 2.3 respectively and show that there was a slight tendency for inaccuracy on the far-near dimension to rise relatively with age, but that this rise was small

and again insignificant. As will be seen from Table 2.2 the percentages of over- and under-corrections also showed little consistent change with age. We can therefore say that, so far as the measures in this experiment go, the introduction of the bar and the resulting complication of the motor task had no appreciable adverse effect on performance in any of the age-ranges tested, and that therefore either this motor performance did not fall off with age among our subjects or adequate compensation was made for deficiencies.

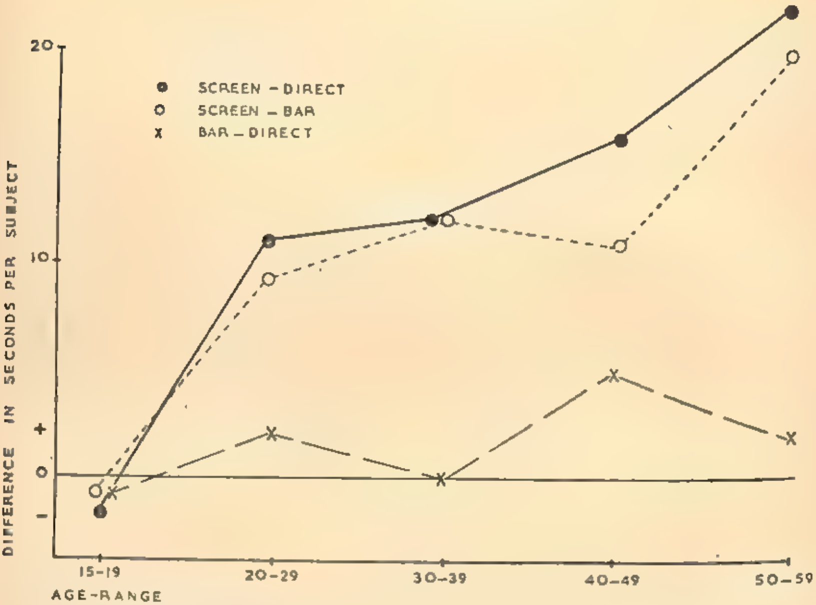

FIG. 2.3. Differences of time taken to throw between the three conditions
The differences between the bar and direct conditions were small and irregular. Those between the screen and bar conditions were larger and rose fairly consistently with age.

Some compensation of this kind did in fact appear to be taking place, both in this condition and in direct throwing. It was clear from observations made by the experimenter that there was a change with age in the way the subjects approached the tasks. The subjects in the 'teens and twenties tended to approach the experiment in a somewhat happy-go-lucky manner, and, while seeming interested in doing their best, did not appear to make any great effort to do so. The subjects in the later age-ranges showed a much more keenly concentrated and careful effort.

TABLE 2.2. *Percentages of error due to under- and over-corrections*

Condition of throwing	*Type of correction*	*Age-ranges* 15–19	20–9	30–9	40–9	50–9
Far-near dimension						
A (Direct) .	Under .	20	21	21	21	18
	Over .	37	31	34	38	34
B (Bar) .	Under .	18	21	25	17	22
	Over .	35	36	28	36	38
C (Screen) .	Under .	*32*	*33*	*36*	*39*	41
	Over .	*21*	*21*	*15*	*15*	12
Left-right dimension						
A (Direct) .	Under .	27	22	23	26	21
	Over .	22	18	20	18	24
B (Bar) .	Under .	25	26	25	25	22
	Over .	22	25	23	21	25
C (Screen) .	Under .	*29*	*33*	*25*	*27*	22
	Over .	*20*	*22*	*22*	*23*	27

In the screen condition the percentage of error due to under-correction on the far-near dimension tended to rise with age but the percentage due to over-correction tended to fall. These trends were reversed on the left-right dimension. No consistent trends were observed in the direct and bar conditions.

The results obtained for *throwing over the screen* (condition C) showed more striking changes associated with age which may be classed under four heads:

1. *Accuracy.* As will be seen from Fig. 2.1 the far-near inaccuracy was very much greater in all age-ranges than in the other conditions. In contrast, the left-right inaccuracy showed comparatively little increase, and it seems clear, therefore, that the changes which occurred in this condition were the result of the mirror effect which displaced the view of the target in space and reversed the far-near dimension. The left-right dimension remained, of course, unreversed by the mirror and it was possible for subjects to get some help in aiming in this dimension by aligning points on the top edge of the screen with the view of the target in the mirror—a secondary cue not available for aiming in the far-near dimension.

Comparing the different age-ranges, it can be seen from Fig. 2.1 that there was a pronounced rise in the far-near inaccuracy from the thirties to the fifties. This absolute rise is, however, of less interest than the rise with age of the *differences* between inaccuracy in this condition and in throwing over the bar (i.e. between conditions C

and B). Since the motor task of throwing over the bar was the same as that involved in throwing over the screen, we may take it that these differences were the result of the complication of the perceptual task. It will be seen from Fig. 2.2 that they were substantially higher for the forties and fifties than for the younger age-ranges.

2. *Time taken.* The differences in time taken between throwing over the bar (condition B) and over the screen (condition C) are set out in Fig. 2.3, from which it will be seen that there was a rise in the differences from the 'teens to the twenties and another rise from the forties to the fifties.

Considering accuracy and time together, it appears that the complication of the display caused more difficulty to the older than to the younger subjects, this difficulty being manifested in the twenties by a rise in time taken, then in the forties by a fall in accuracy, and finally in the fifties by another rise in time taken. It is clear that the increased difficulty could not have been a matter of failing vision, since this should have shown itself in all three conditions more or less equally. Indeed, the mirror should, if anything, have favoured subjects with a tendency to presbyopia by adding some 4 feet to the distance between the eye and the display without seriously reducing the retinal size of the latter. It is also clear that it could not have been due to failure of the effector mechanisms, since the motor requirements were the same in throwing over the screen as in throwing over the bar.

The nature of the difficulty was presumably that the relationship of the display to the effector action required was an unusual one, demanding effort on the part of the subjects in giving the display meaning. The data provided by the display required some 'manipulation' or reorganization before they could be used as the basis of an appropriate response—the far-near dimension had to be reversed, and the whole display referred to a point in space other than that at which it was seen. It appears, therefore, that the locus of the increased difficulty shown by the older subjects in dealing with the conditions of throwing over the screen must lie within the central mechanisms, somewhere between the points at which the stimulus is received and at which effector action is initiated—that is, essentially on the receptor side.

How far this difficulty was due to the display being unusual, and how far to its requiring 'manipulation', it is impossible to say on present evidence. It is relevant to point out, however, that experience of mirrors increases with age, so that reference to the mirror-effect

would appear to be inadequate without simultaneous reference to the reorganization of the visual field that it makes necessary before an appropriate effector response can be made.

The other two changes with age noted in the performances of subjects when throwing over the screen appeared to be related to each other but not to the absolute degree of accuracy attained:

3. There appeared to be a significant difference between the age-ranges in the *type of error* made. It can be seen from Table 2.2 that on the far-near dimension the percentage of error due to under-corrections was not only higher for all age-ranges when throwing over the screen than when throwing direct or over the bar, but that it rose consistently with age. At the same time the percentage of error due to over-corrections was not only lower for all age-ranges but fell with age. The amounts by which the percentages of error due to under-corrections exceeded those due to over-corrections are shown in Fig. 2.4. It seems clear that the older subjects were making smaller corrections for their errors. In other words, they were displaying a kind of 'rigidity' by tending to throw successive chains to the same part of the target.

The scores for the left-right dimension in Table 2.2 showed trends which were on the whole opposite to those for the far-near dimension. Thus the percentage of error due to under-correction tended to decrease but that due to over-correction tended to increase with age, although the tendencies were not statistically significant. The differences between these percentages are also shown in Fig. 2.4. It would seem that the older subjects were compensating for their lack of correction on the difficult far-near dimension, by relatively greater correction on the more readily comprehended left-right dimension.

4. There was an interesting difference between the age-ranges in the manner of picking up the chains to throw. When throwing direct or over the bar, subjects of all ages tended, while picking up each chain, to look away from the target towards the stand on which the chains were hung. When throwing over the screen, however, many of the subjects tended to keep their eyes fixed on the mirror and to pick up the chains by 'feel'.

On the basis of observations made when throwing over the screen the subjects were divided into those who always or almost always looked while picking up the chains, and those who seldom or never did so. The results of classifying the subjects in this way are shown

in Fig. 2.5, from which it will be seen that the tendency to look for the chains when picking them up increased strikingly between the twenties and the thirties.

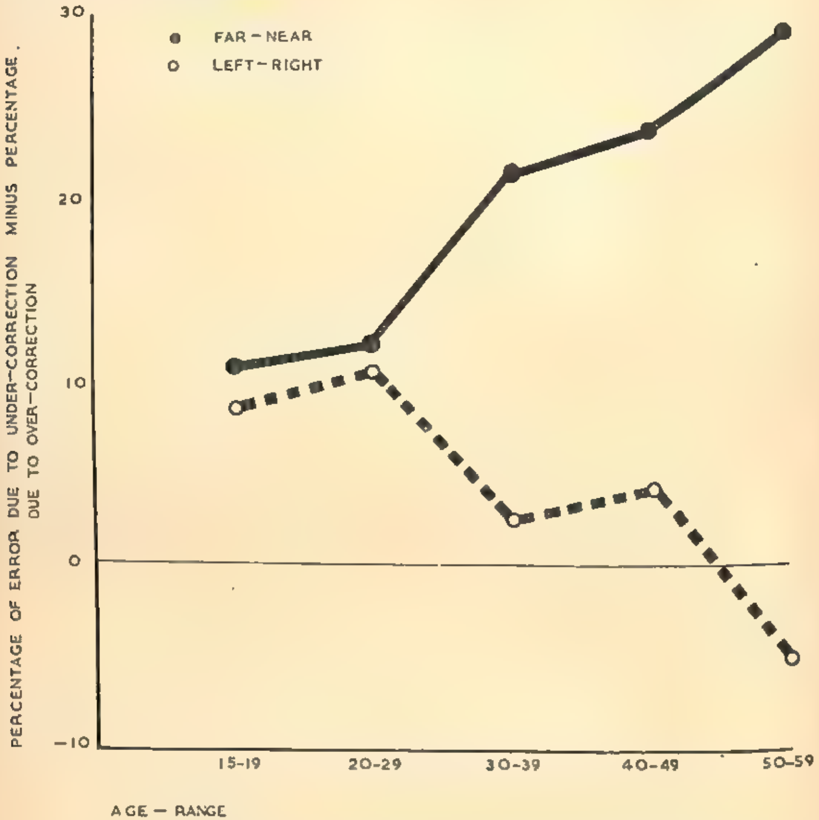

FIG. 2.4. Throwing over the screen. Differences between the percentages of error due to under- and over-correction

On the far-near dimension the percentage of error due to under-correction became progressively greater than that due to over-correction as age increased. The opposite tendency was shown on the left-right dimension.

Experiment 3

The difference of behaviour between older and younger subjects when picking up the chains had not been expected when the experiment was planned, and the accuracy of recording the occasions on which the subjects looked, or did not look, for the chains was not sufficient to merit more than the rough classification which is the basis of Fig. 2.5. Accordingly, a second experiment was undertaken

with this point specifically in mind. Fifty-two new subjects, half in their twenties and half in their thirties, were obtained from the same sources as those who took part in the original experiment, and each was required to throw two groups of fifty chains over the screen. One group of fifty had to be picked up in a regular pattern on a board, the

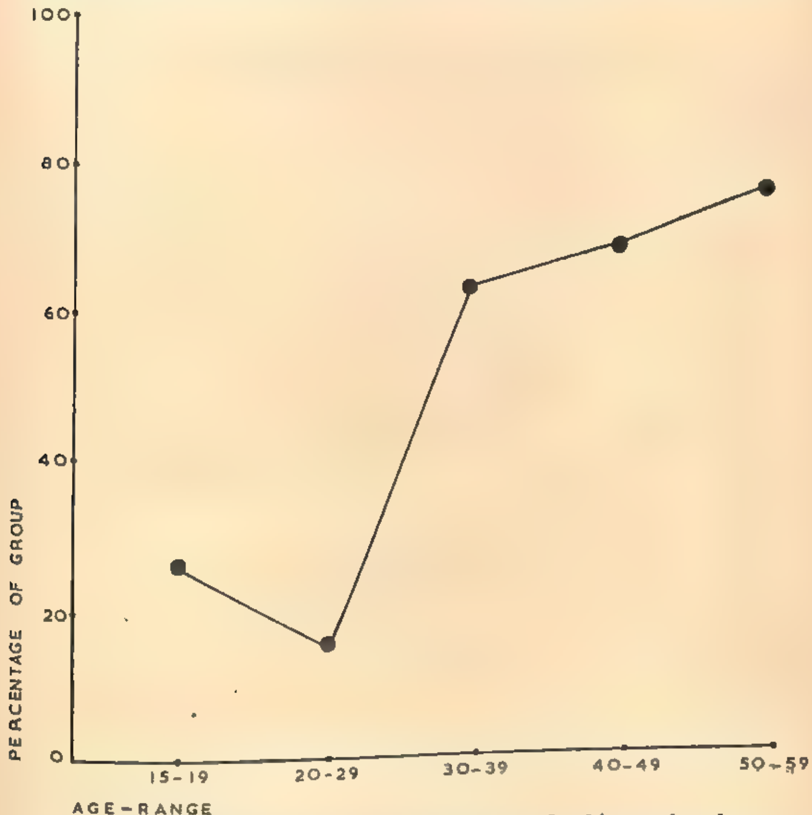

FIG. 2.5. Throwing over the screen. Percentages of subjects who always or almost always looked for the chains when picking them up to throw.

The percentage of subjects who tended to look for the chains increased strikingly between the twenties and thirties

layout being such as more or less to compel a subject to look towards the board each time he picked up a chain. The other group of fifty were handed by the experimenter to the subject one by one as he threw, so that there was no need for him ever to take his eyes off the mirror—all he had to do was to hold out his hand and the experimenter placed a chain in it. To balance practice-effects, half the

subjects in each age-range threw their first fifty chains picking them up from the board and their second having them placed in the hand by the experimenter. The other half received the treatments in the reverse order.

The experimenter stood to the side of, and slightly behind, the subject, and noted for each chain whether the subject looked for it or not.

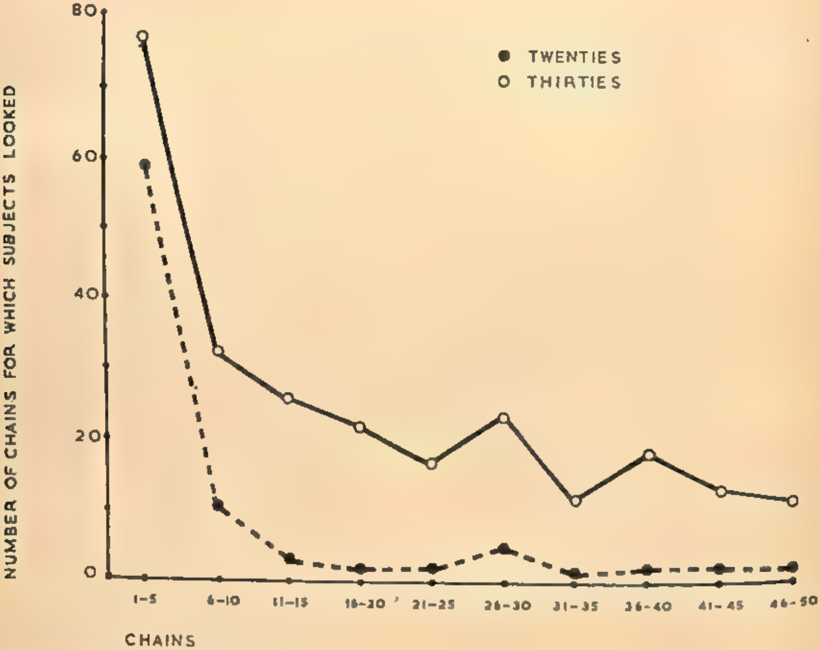

FIG. 3.1. Numbers of chains for which subjects looked when there was no need to do so

The ordinate represents numbers per 26 subjects for each group of five chains. The subjects in their thirties looked substantially more frequently than those in their twenties.

As was to be expected, almost all the subjects in both the age-ranges looked away from the mirror every time when picking up the chains from the board. The results obtained when the chains were handed to the subjects were, however, very much less uniform. They are shown in Fig. 3.1, from which two interesting points emerge.

1. The subjects in both the age-ranges tended to look away from the mirror towards their hands when receiving the first few chains of the series. This tendency, however, rapidly diminished, indicating that as the subjects became familiar with their task they gave their

main attention to the reflection of the target in the mirror, and carried on the task of receiving the chains with reduced sensory cues—i.e. they were doing by touch what they were before doing by touch supplemented by vision.

2. In spite of this, the results strikingly confirm those of the first experiment in that the subjects in their thirties did, on the average throughout the series, more frequently look round when receiving the chains than did those in their twenties. Furthermore, this appeared to be a fairly general tendency. Table 3.1 sets out the subjects in the two age-ranges according to the number of times each looked round. It will be seen that no subject in the twenties looked round more than nine times in all or twice after the first ten chains, as against some 35–40 per cent. of the subjects in their thirties.

TABLE 3.1. *Frequency of looking for chains when there was no need to do so*

		Frequency of looking for chains											
Chains	*Age-range*	*0*	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*Over* 10
1–10	Twenties	4	2	9	4	2	3	1	1	..	..	..	..
	Thirties	3	1	4	4	4	4	..	1	2	..	3	..
11–50	Twenties	18	4	4	..	..	..	..	..	..	..	..	..
	Thirties	10	3	3	..	1	..	1	1	3	1	1	2
All	Twenties	4	2	7	5	3	..	1	2	1	1	..	..
	Thirties	3	..	3	2	2	4	2	..	1	..	1	8

The numbers in the table are the numbers of subjects who looked 0, 1, 2, 3, &c. times.

There was a substantial tendency for the subjects in their thirties to look more frequently than those in their twenties.

The number of times subjects looked round when receiving chains in this experiment was almost certainly less than the number of times they looked while picking up chains in the first experiment, since in the second there was very much less need to do so. The percentages of subjects who looked less than five times in all were, however, almost exactly the same as the percentages of the corresponding age-ranges on the first experiment classed as 'seldom or never looking' for the chains.

There was no significant difference of accuracy between the two conditions.

The explanation of the change of behaviour with age when picking up the chains in these two experiments is not at all easy to see. From

the evidence in Table 3.1 and Fig. 3.1 it would seem possible that the older subjects were less able, or at any rate less willing, to pick up or receive the chains by reduced sensory cues, i.e. without seeing as well as feeling what they were doing.

Statements by many subjects in the second experiment made it clear that they recognized that keeping one's eyes on the target had advantages for aiming because posture and orientation were maintained. On the other hand, some said they disliked having the chains handed to them because it made them feel hurried, and disturbed their confidence, and a few subjects maintained that they preferred to look away from the target because prolonged fixation of one point resulted in the field of vision 'becoming blurred' or their 'seeing everything double and shaky'. As one of them said: 'It is, I think, an obvious and well-known fact that looking at one point for a while is bound to tire one's eyes. It is always easier to look at, and to see, a fresh point, even if this point was looked at and seen before.' We cannot, it would seem, base an explanation on the feelings of being hurried, because these arose only in the second experiment, and were absent in the first (in which the subject was entirely free to pick up the chains in his own time). The remarks about the effects of prolonged looking at the target indicate, however, that at least in a few cases this appears to have induced some perceptual disorganization or fatigue. The possibility has to be considered that this arises more easily in older subjects than in younger, and that looking away from the target while picking up the chains represented an active, although in all probability largely unconscious, attempt to dissipate these effects.

While the first of these two explanations seems the more conservative, we cannot on the present evidence definitely prefer it to the second. The two are, of course, not mutually exclusive.

Experiment 4

TRACING FIGURES

The last three experiments have been concerned with skills into which both accuracy and speed have entered, but the main stress has been laid on accuracy. In the present experiment an attempt was made to provide a task in which the requirements for accuracy were less stringent so that the stress was more upon speed. Both speed and accuracy do, of course, enter into almost all manipulatory skills and the stress laid upon one or the other can to some extent be altered by instructions to the subject. When, however, instructions for both

accuracy and speed are given, the relative stress would appear to depend largely upon the nature of the task. If the tolerance-limits of accuracy are narrow (as, for instance, in the grid-matching experiment) it is to accuracy that the subject gives his main attention. If they are wider, as in the present experiment, he gives more attention to speed.

The nature of this experiment may best be understood from an outline of the procedure. This consisted of six stages, as follows:

1. The subject wrote the figures 1, 2, 3, 4, 5, 6, 7, 8, 9, 0 once on a piece of paper, the experimenter timing the performance by stop-watch.
2. The subject was presented with an aluminium plate (see Fig. 4.1*a*) in which were inlaid in brass the ten figures 1 to 0, and was required to trace over them with a stylus five times, 'as quickly and accurately as possible'. The figures were $2\frac{3}{8}$ inches high and the strips forming them were $\frac{1}{2}$-inch wide. Each figure was divided into six sections. Electrical circuits were made through the plate and stylus to an apparatus which rang a bell as soon as the subject had traced over all six sections of a figure, the bell thus signalling that the task of tracing that figure had been completed and that he should pass on to the next. The circuits were arranged in such a way that the order of tracing over the various sections was immaterial, so that the subject was left free to trace the figures in any way he liked. If, at any point, he made an 'error' by running the stylus over the edge of a figure on to the surrounding aluminium plate, a buzzer sounded. The times for tracing each figure and between finishing one figure and beginning the next were recorded by pens marking on a paper strip running over a constant-speed drum.
3. The subject wrote the *mirror-images* of the figures 1–0 once on paper. The experimenter again timed this performance by stop-watch as in the first stage.
4. A plate with mirror-image figures was presented, and the subject traced them five times. The construction of the plate, which is shown in Fig. 4.1*b*, and the arrangement of the task were similar to those used in the second stage.
5. Mirror-images of the figures 1–0 were written a second time—i.e. the third stage was repeated.

6. The subject again traced the figures 1–0 five times the normal way round—i.e. the second stage was repeated.

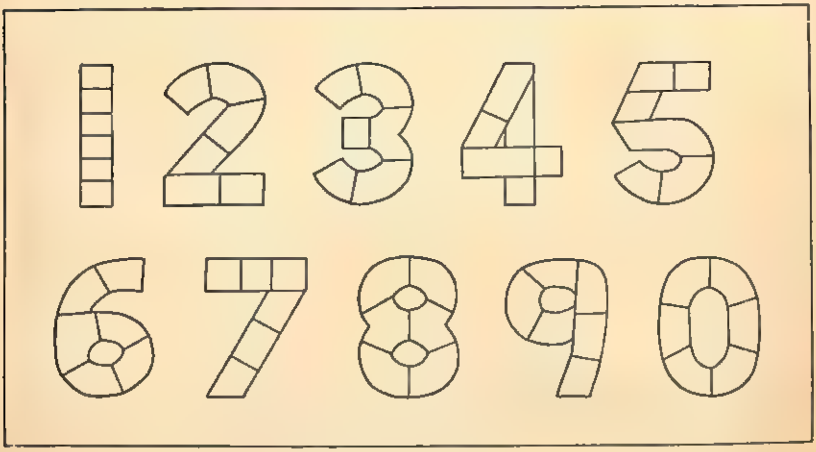

FIG. 4.1*a*. Diagram of plate with normal figures used in tracing-task.

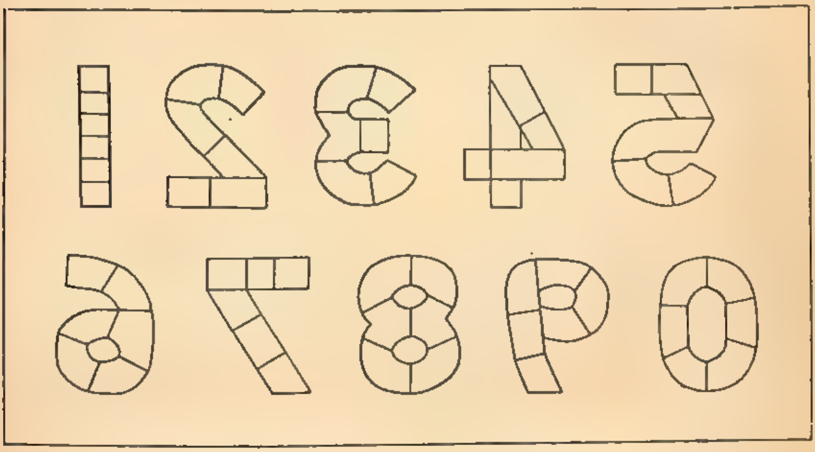

FIG. 4.1*b*. Diagram of plate with reversed figures used in tracing-task.

For our present purpose the main interest lies in the results from the tracing-stages, and it is almost entirely with these that we shall deal. The writing-stages were inserted mainly as an experimental control—to give an indication of performance in the absence of clearly displayed patterns for the guidance of the hand-movements required. The essential difference between the tasks presented in tracing and

writing would seem to be that, in the former, movements have to be made in accordance with a clearly shown external 'display', but in the latter the subject has, as it were, to provide his own 'imaginary' display for guiding his movements. Thus the main limitation of a subject's performance in tracing lies in the actual making of the required movements, whereas in writing it lies in deciding what movements to make.

The sixty-five subjects ranged from the twenties to the seventies. Of those in the twenties, half were students and half naval ratings. About half the subjects in the thirties, forties, and fifties came from evening clubs and classes at a Cambridgeshire Village College. The remaining subjects were recruited from a village in Sussex by a relative of the writer and included many who had previously taken part in the grid-position matching and the preliminary throwing-at-a-target experiments. The numbers of subjects in each decade were as follows:

Age	*No.*	*Age*	*No.*
20–9 . . .	12	50–9 . . .	14
30–9 . . .	10	60–9 . . .	14
40–9 . . .	9	70–9 . . .	6

Results

The mean times per 'run' of ten figures (1–0) in the tracing-stages of the experiment are shown for the various age-ranges in Fig. 4.2. Five points about these times seem worthy of note:

1. The average times per run rose strikingly with age, although the rise was not entirely continuous. The times taken by the subjects in their twenties and thirties were very similar. There was then a rise of about 40 per cent. to the forties and fifties, followed by further rises to the sixties and seventies.

2. Together with the increase with age of time taken went a very substantial increase in the variability between subjects, as shown by the standard deviations for the various decades set out in Table 4.1. Among the subjects in their sixties and seventies this variability was very marked indeed: some subjects were taking very long times, and others were attaining speeds comparable with those of subjects in the twenties. The seventies, for instance, contained the slowest subject of the whole group, who took 586 seconds to complete the fifteen runs, but also contained the third quickest, who took only 147 seconds and whose speed was exceeded only by two students in their twenties.

3. Comparing the times taken over the first run with those taken later in the series, we see that the subjects in all the decades became quicker as the experiment proceeded, and that the drop in time tended

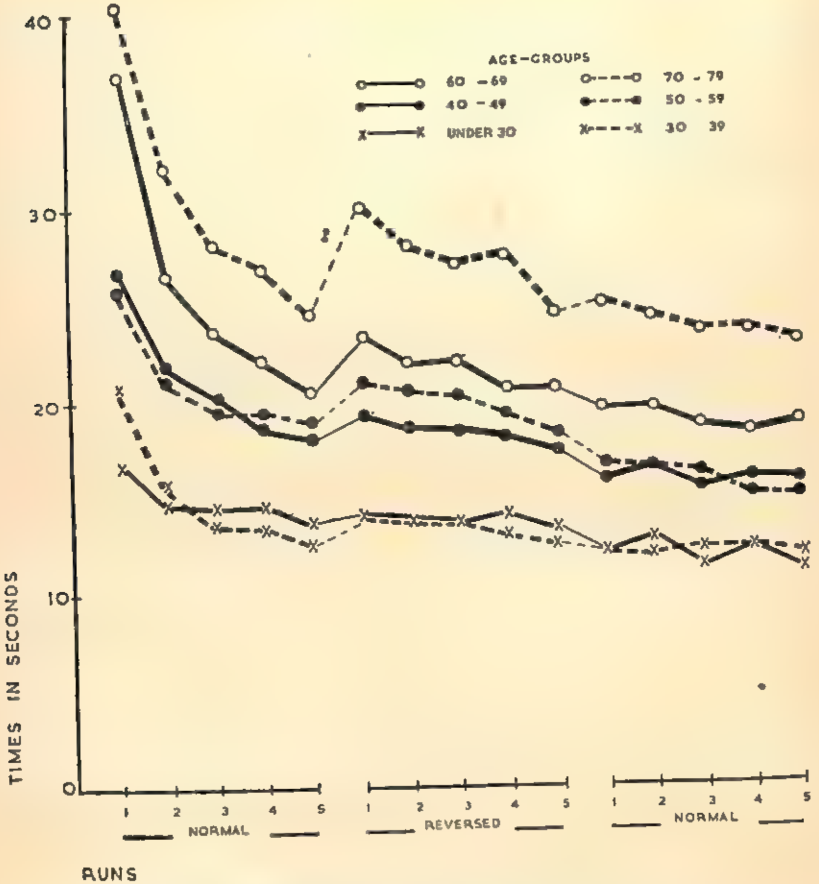

FIG. 4.2. Times taken per subject to trace ten figures (1–0)

The subjects in their forties and fifties were substantially slower than those in their twenties and thirties. The subjects in their sixties and seventies were still slower.

to increase with age. In terms of the absolute time taken, therefore, the older subjects were substantially slower as compared with the younger in the first run than they were subsequently. The meaning of this finding is, however, not easy to assess because the *proportional* drop in time did not vary greatly or very consistently with age.

TABLE 4.1. *Standard deviations of times taken for 15 'runs' of ten figures (1–0)*

Age-range	*Standard deviation in seconds*
20–9	42
30–9	51
40–9	92
50–9	89
60–9	100
70–9	174

There was a striking tendency for variability between the times taken by different subjects in the same age-ranges to be greater in the higher age-ranges than in the lower.

4. The older subjects tended to take longer than did the younger over the first run on the reversed figures relatively to the previous run on the figures the normal way round. In other words the older subjects were slowed down more than the younger on meeting the new plate for the first time. This finding is in line with the suggestion, made in the case of the grid-matching experiment, that the older subjects there took longer than the younger to deal with changes in the display; and it is supported by the fact that before beginning to trace each reversed figure the subjects, especially the older subjects, tended to hesitate slightly as if to 'get clear' what movement to make.

Additional evidence that it was the change of display which was affecting the older subjects when tracing the reversed figures came from the observation that they usually regarded them as normal figures reversed and traced them as such, whereas the younger subjects tended to regard them as 'nonsense' figures and to trace them in whatever way seemed most convenient—a tendency indicating a less 'rigid' approach to the display.

The times for tracing the reversed figures do, however, as a whole show that the reversal of the display did not have a substantial effect on the speed of performance in any age-range except, perhaps, the seventies. In this respect the tracing-times were in striking contrast to the times for writing figures. From Table 4.2 it will be seen that the first time the subjects wrote the reversed figures they took about three times as long as they took to write them the normal way round. When they wrote the reversed figures a second time they were considerably quicker, but on the average still took nearly twice as long. It thus

appears that in the tracing-task we were measuring effector performance relatively uncomplicated by any requirements for 'organizing' or comprehending the display.

TABLE 4.2. *Times taken in seconds per subject to write ten figures (1–0) once*

Age-range	*Normal way round*	*Reversed, first time*	*Reversed, second time*
20–9	7·3	21·3	12·4
30–9	7·7	20·3	14·5
40–9	9·3	33·8	20·9
50–9	7·7	31·9	22·8
60–9	11·7	34·9	25·1
70–9	12·5	55·5	37·2

The subjects in all age-ranges were very much slower writing the figures reversed than normal way round.

5. Although the average times shown in Fig. 4.2 indicate clearly that there was a substantial fall of speed with increasing age among our subjects, the nature of the changes involved is apparent only when the information about times taken is supplemented by information about 'errors', i.e. occasions when the subject let his stylus go over the edges of the figures on to the surrounding plate.

The mean numbers of errors made during the fifteen tracing-runs by the various age-ranges are shown in Fig. 4.3. It will be seen that the errors rose from the twenties, to a peak in the thirties, fell during the forties and fifties, and remained low in the sixties and seventies. Within each age-range except the highest there was a tendency for time taken and errors made to be inversely related, the quicker subjects tending to make more errors than the slower. By comparing Figs. 4.2 and 4.3 it will be seen that—apart from the fifties, who are both relatively fast and very accurate—the same is broadly true of the different age-ranges from the thirties onwards.

It appears, therefore, that from the thirties onwards the performance of our subjects differed not only in speed but also—perhaps mainly—in the balance they struck between speed and accuracy. The subjects in their thirties appeared to maintain the speed of those in their twenties, but at the expense of accuracy. From the forties onwards accuracy was restored at the expense of speed. This finding is in line with those of the grid-matching experiment, where the older subjects tended to be slower but more accurate than the younger.

Discussion of the results

Although it seems clear that in the tracing-task we are dealing with a change of effector performance between younger and older subjects, it is by no means clear how far the slowness of the latter can be attributed to a deficiency in the effector mechanisms. A task such as this

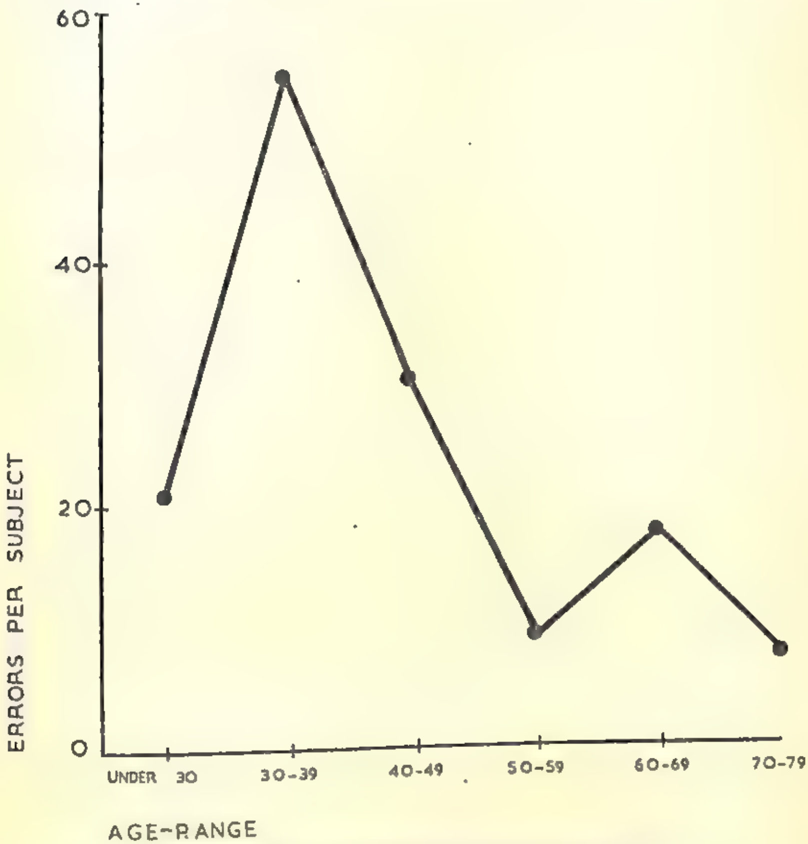

FIG. 4.3. Errors made during all 15 tracing-runs

The average number of errors rose sharply from the twenties to the thirties but fell again in the higher age-ranges.

illustrates well the serial aspect of skill. The subject is required not only to make a movement but to make it in a controlled manner by limited amounts first in one direction then in another, according to the shape of the pattern he is tracing—in other words according to the dictates of the display. From split second to split second he has to make

changes of direction and speed which depend upon the direction and speed of his movement in the immediate past and the point to which these have led him. His effector action at any time is thus dependent upon *knowledge of the results of what has already been done*—in other words on the *perception* of the relationship of his present direction, speed, and position to the display, i.e. upon a *receptor* function.

This is true whether the display is complicated and requires 'organization' and comprehension, or whether it is simple and straightforward as in the present instance. In consequence, we cannot assume that in a task where the display is simple and straightforward the effector performance will be limited only by the efficiency of effector mechanisms. Even the simplest effector action which is carried out in a controlled manner in relation to a display will be very largely dependent upon receptor functions, and changes of effector *performance* may be in no way indicative of changes in the effector *mechanisms*. In the present instance it is essentially upon the control of effector by receptor functions that accuracy depends, as is evidenced by the compensatory relationship between accuracy and speed.

Just how much of the slowness of our older subjects is to be accounted for in this way, and how much must be regarded as due to true effector changes, we cannot at present say. The problem is of obvious importance not only in relation to the present task, but over a very wide field of skilled performance, and we are planning further experiments from which we hope to gain a closer knowledge.

Before passing to the next experiment it seems desirable to mention one further finding which may be due to a coincidence, but which nevertheless suggests an interesting link between our tracing-task and a number of other recent studies of rapid skilled performance (e.g. Vince 1948, 1949). These studies have used subjects almost all of whom were in their late 'teens and twenties, and have indicated that amongst these subjects there is a fairly definite 'ceiling' speed of performance. It appears that the maximum number of discrete units of performance which can be handled is in the neighbourhood of two per second—120 per minute—and that higher speeds than these can be attained only by grouping the units into larger wholes so that two or more units can be treated as one.

The assessment of the number of discrete units of performance in tracing the figures cannot be made with certainty, but two reasonable estimates seem possible. If we take the beginning and end of each

figure and every abrupt change of direction within a figure (e.g. at the bottom of '2' or the top of '7') as marking the beginning of a fresh unit of performance, the total number of units per run of ten figures

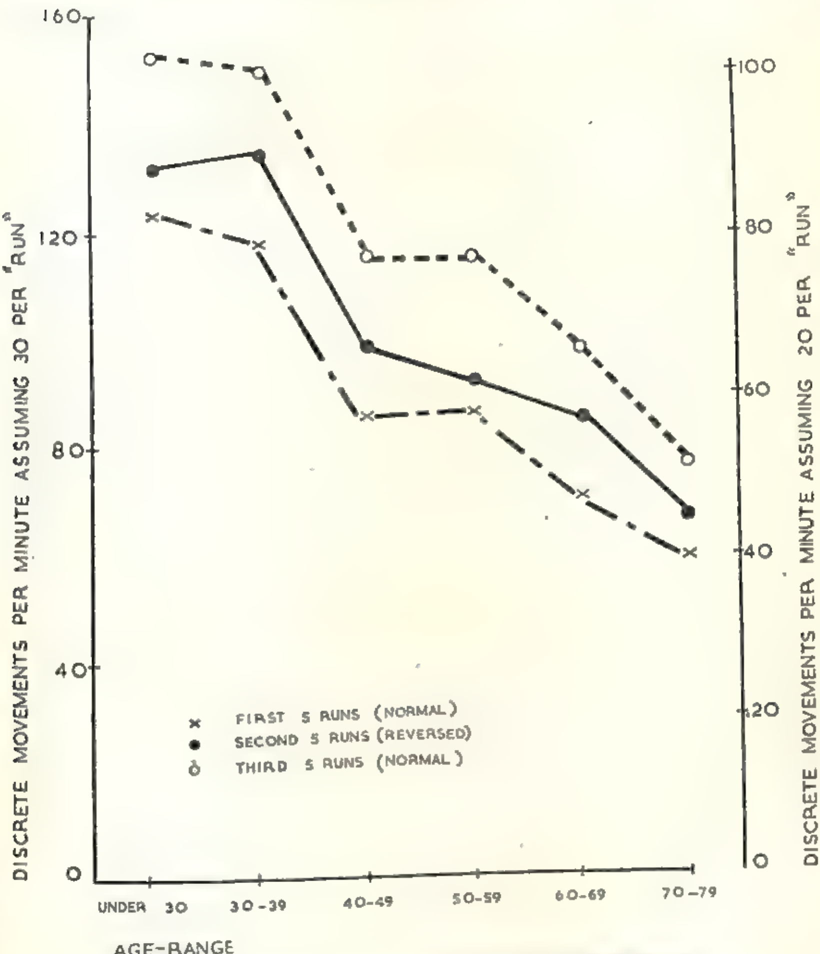

FIG. 4.4. Discrete movements per minute in tracing-task

(1–0) comes out at about 30. If, on the other hand, we can assume that each figure is dealt with as a single unit in spite of abrupt changes of direction, this number is reduced to 20—i.e. the beginning and end of each figure.

In Fig. 4.4 the numbers of discrete units of performance per minute

according to these estimates are plotted for the various decades in each of the three tracing-stages of the experiment. It will be seen that the rates for the subjects in their twenties all lie a little above 120 per minute on the higher estimate and somewhat below on the lower. If a moderate amount of grouping can be assumed in the later stages of the experiment—as indeed appeared to be the case from the experimenter's observations—the results seem to be in very fair agreement with the 'ceiling' rate found by previous workers.

Also in agreement are the times taken by the quickest subjects. At the lower estimate the maximum rate at which five runs can be performed should be in the neighbourhood of 50 seconds. In fact, only one subject—a student in his twenties—attained a time less than 46 seconds.

The average rates attained by the subjects over 40 fell substantially below 120 per minute, and it seemed possible to us that there exists a tendency as age increases for the 'ceiling' rate to become lower. We do not wish to stress this point here, because the rates given in Fig. 4.4 are based only on the times taken, and we do not know how far they ought to be modified to take account of errors. We mention it, however, because it provides a suggestive link with the next experiment, in which a similar result appeared.

Experiment 5

TRACKING EXPERIMENT

In this experiment the subject attempted to keep a pointer, which he could move from side to side by means of a handle, in line with a second pointer moved irregularly from side to side by the apparatus. This type of task had been used in many service experiments during and since the war (e.g. Carpenter 1950, Mackworth 1950). It is of interest here because it is complementary to the figure-tracing task. The subjects in the figure-tracing experiment were working under *pressure for speed* in the sense that they were encouraged to carry out the task as fast as possible. The timing of the performance was, however, under their own control, and if at any point they were slow this did not result in an increase of error. The *constraint* placed upon them was not one of having to carry out the task within a given length of time, but of having to complete each portion of the task, i.e. each figure, before passing on to the next. In the present experiment the subject was not compelled in this way, but if at any point he was slow

and did not keep up with the movements of the pointer operated by the apparatus he inevitably made errors. In other words, while the figure-tracing experiment imposed what may be termed *speed pressure*, the subject's performance in the present experiment was *paced* by the display.

In terms of receptor and effector organization the task was very simple, because both the changes in the display and the actions required were simple and straightforward. The demands of the task essentially lay not in its complexity, but in the rigid time-limits allowed for its performance.

Apparatus

The subject stood facing a wooden box, the top of which was 20 inches wide, 15 inches from front to back, and about 3½ feet from the floor. Two vertical rods, each topped by a nut ¼-inch square and painted white, projected about ½-inch upwards through a slot near the front edge of the top of the box. One of these rods, or 'pointers' as we may conveniently call them, was moved from side to side by means of an irregularly shaped cam inside the box, and formed the 'target'. The other was about 1 cm. nearer the subject than the first, and could be moved from side to side by a handle. This was mounted at the right of the box and projected forwards to a convenient position for operation by the subject's right hand.

The cam was shaped in such a way that the motion it imparted to the target-pointer could be regarded as consisting of a series of 80 approximate quarter-sine waves, each with an amplitude roughly proportional to its wavelength. The target-pointer thus made 40 reversals of direction—i.e. swung 20 times each way—during one revolution of the cam. The average swing was about 1·6 cm., which subtended an angle of about 1½ degrees at the subject's eye. The speed of the cam could be varied from a little under 1 to a little over 4 revolutions per minute.

The handle, which, as we have said, projected towards the subject from the right-hand end of the box, was 2 feet long. It pivoted freely in the vertical plane and was light to manipulate. It was connected to the subject's pointer in such a way that raising it made the pointer move to the right and lowering it made the pointer move to the left, the extent of movement at the end of the handle being about 2½ times that of the display.

The subject's pointer was connected to a scoring-device which recorded the following information:

(*a*) Misalignment of the two pointers in units of time × distance which could be converted into millimetre-seconds.

(*b*) Reversals in the direction of swing.

(*c*) Extent of movement of the subject's pointer.

(*d*) Two scores from which could be computed the mean phase-lag, and from this the mean time-lag, of the subject's pointer relative to the target-pointer.

All these scores were read each revolution of the cam without, however, interrupting the subject's performance. This was done by changing automatically at the end of each revolution to a duplicate scoring-device.

Subjects and procedure

The 50 subjects were divided into two groups—25 in the late 'teens and twenties, and 25 over 30. Of the older subjects 2 were in their thirties, 5 in their forties, 4 in their fifties, 10 in their sixties, 3 in their seventies, and 1 in his eighties. The younger subjects were naval ratings. The older were a group recruited by a relative of the author from among friends and acquaintances and were probably of a somewhat higher occupational status than the younger subjects, but it was thought that this would not seriously impair the validity of a comparison on this type of task.

Each subject was shown the motion of the two pointers and told that his task was to keep them in alignment. He was then allowed to try the handle, and upon his pronouncing himself satisfied that he understood what to do, was given the following task:

2 revolutions of the cam at a speed of 1 revolution in 64 seconds.
2 revolutions of the cam at a speed of 1 revolution in 37 seconds.
4 revolutions of the cam at a speed of 1 revolution in 24 seconds.
4 revolutions of the cam at a speed of 1 revolution in 19 seconds.
4 revolutions of the cam at a speed of 1 revolution in 16 seconds.

The whole task was done without a break, the four changes of speed being made during four unscored revolutions of the cam. To balance practice and fatigue effects, the various speeds were given in different

orders to different subjects. The subjects were warned each time the speed was changed that they were going to be 'speeded up' or 'slowed down'.

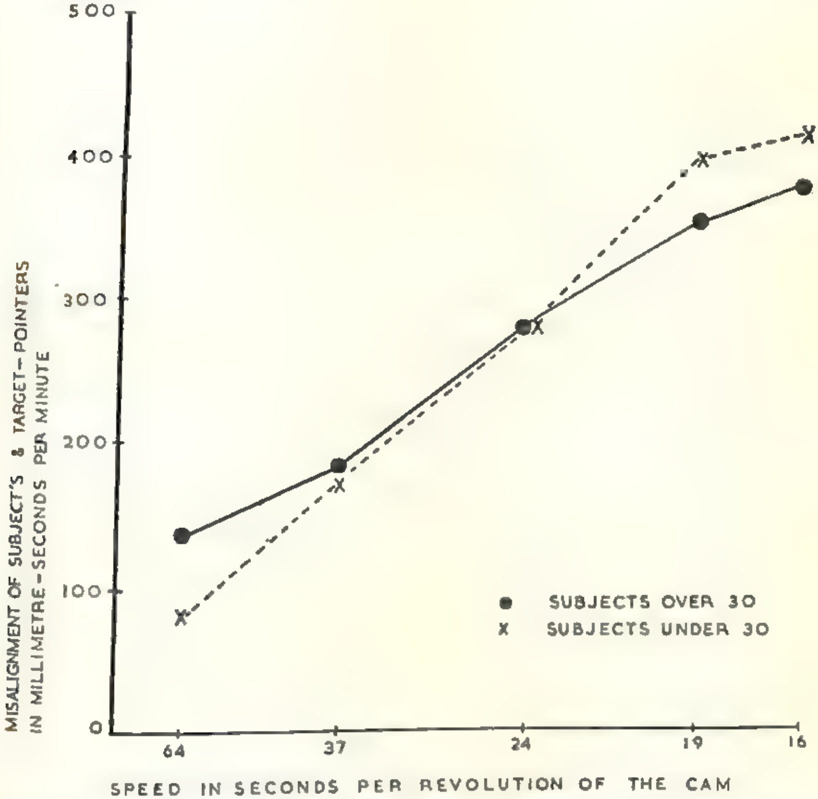

FIG. 5.1. Average time × distance 'off-target'

Misalignment increased markedly with speed. The older subjects were substantially less accurate than the younger at the lowest speed, but were little different from the younger at speeds above the lowest.

Results

1. *Misalignment.* The average scores for time × distance 'off-target' per minute are shown in Fig. 5.1 for the two age-ranges at each of the five speeds. It will be seen that:

(*a*) The amount of misalignment rose greatly with speed, indicating that accuracy of tracking was markedly poorer at the higher speeds than at the lower.

(*b*) The older subjects were substantially—about 67 per cent.—less accurate than the younger at the lowest speed, but at speeds above this there was little percentage-difference between the two groups. It may be remarked that the author noted at the time the experiment was done that the older subjects appeared to track relatively poorly at the low speeds and relatively well at the high.

The similarity between the two age-groups at the high speeds was a most unexpected and surprising result, but it should be borne in mind that the misalignment score has the status of a *measure of overall achievement*, and needs to be supplemented by the scores we discuss below for certain *aspects* of the performance which indicate how this overall achievement was attained.

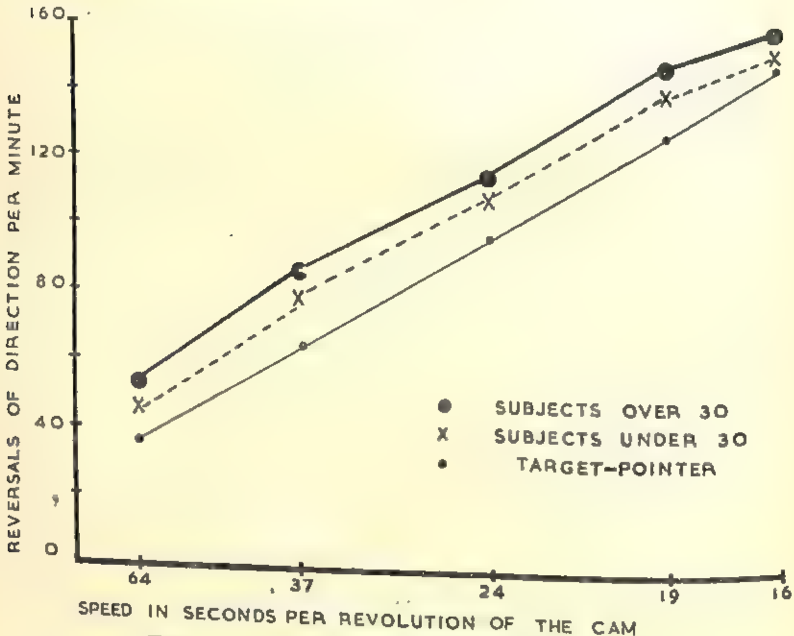

FIG. 5.2. Average number of reversals of direction
The scores for the older and the younger subjects were very similar. Both made a few more than the correct number of reversals at all speeds.

2. *Reversals of direction.* The average numbers of reversals per minute made by the two age-ranges at each of the five speeds, together with the correct number at each speed, are set out in Fig. 5.2.

It will be seen that the scores for the younger and older subjects were very similar. Both made a few more reversals than the correct number—owing to 'false turns'—but both kept fairly closely to the correct number at all speeds.

This finding confirms the observations of the author that almost all the subjects were making a real effort to track at all speeds, although doing so at the two higher speeds was clearly a severe strain. At these speeds the subjects appeared tense, and when the experiment was over many of them made spontaneous remarks such as 'Phew! that was pretty severe. I shouldn't have liked to go on doing that much longer.'

In comment upon such remarks it should be noted that on the average there was no sign in these or any of the other scores of any marked tendency for performance to break down towards the end of the experiment. Nor was there any marked tendency for performance to improve during the experiment: the average scores for the beginning, middle, and end of the experiment were all closely similar.

3. *Extent of movement.* The average distances moved per minute by the subject's pointer and hand are set out in Fig. 5.3, together with the distances which would have been covered if tracking had been perfect. The most noticeable feature of the scores plotted in this figure is that the extent of movement, unlike the number of reversals of direction, did not rise steadily with speed. At the two lower speeds both age-ranges moved a little more than was required by the movements of the target-pointer. Beyond this speed, however, the amount of movement by the older subjects hardly rose at all. The younger subjects increased their movement a little from the second lowest to the middle speed, but made no further rise thereafter.

Considering the subjects' behaviour in relation to the swings of the target-pointer, it is clear that, broadly speaking, the older subjects as they passed from the lowest to the next higher speed maintained the correct *amplitude* of movement by increasing average *velocity.* As they passed to the middle speed and beyond they maintained the same velocity, but the swinging to and fro of their pointer in response to the swings of the target-pointer became progressively less and less as the speed of the cam increased. The younger subjects showed essentially the same change, but for them it came at the middle rather than the second lowest speed.

Failure to maintain amplitude of swing must be regarded as a

breakdown of tracking. On this criterion, therefore, performance by the younger subjects broke down at the two higher speeds, and performance by the older subjects at the two higher and also at the middle speed.

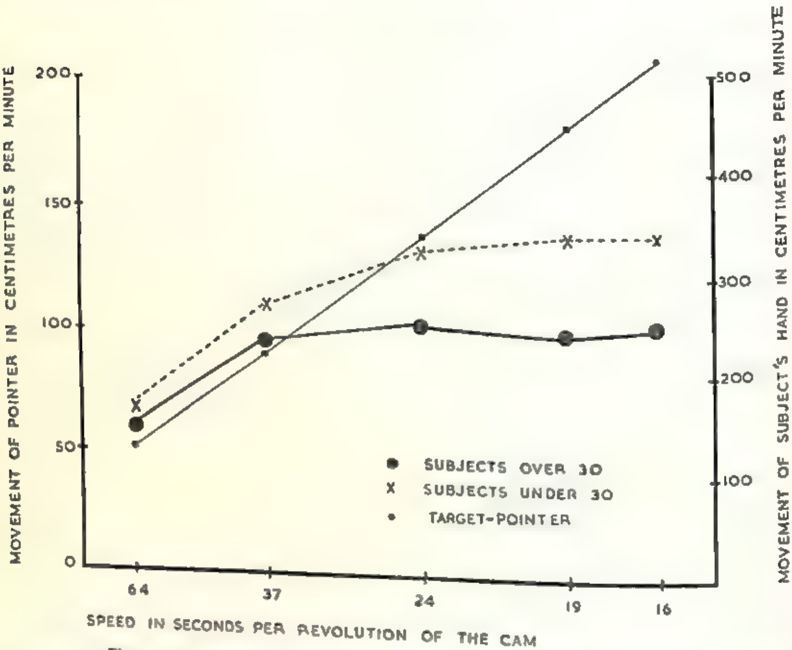

FIG. 5.3. Average distances moved by the subject's pointer
The older subjects maintained amplitude of movement at the two lower speeds, and the younger subjects at these and the middle speed. Beyond these speeds no substantial rises in the amounts of movement occurred.

4. *Phase- and time-lag.* In Table 5.1 the average *phase-lags* are shown for the two groups of subjects at the various speeds.* It will be seen that phase-lag rose greatly with speed and that the older subjects' lag was larger than that of the younger at the two lower and the middle speeds. At the two higher speeds, however, the lags of the two age-ranges were about equal. This equality is of little significance because a phase-lag of over 90 degrees should probably be taken as an indication that tracking was breaking down. From this point of view it is noteworthy that the speeds at which the phase-lags of the two age-ranges passed beyond 90 degrees were the same as those at which they began to show a failure to maintain amplitude of swing.

* For the method of calculating this see the Statistical Appendix.

TABLE 5.1. *Mean phase-lags in degrees*

Speed in seconds per revolution of the cam	*64*	*37*	*24*	*19*	*16*
Subjects over 30	27	55	94	120	129
Subjects under 30	11	31	73	118	134

The older subjects had a substantially greater phase-lag at the lower and middle speeds. The older subjects' phase-lag rose above 90 degrees at the middle speed. The phase-lag of the younger subjects rose above 90 degrees at the second highest speed.

More interesting in many ways than the phase-lags are the *time-lags* of the two age-ranges shown in Fig. 5.4. It will be seen that the younger subjects at the two higher speeds and the older subjects from the middle speed upwards were lagging by an amount between 0·275 and 0·3 second. This is a value which has been found with slight variations by several experimenters as the mean value of the *reaction-time* when the responses to series of stimuli rather than to discrete stimuli have been measured (e.g. Hick 1948, Vince 1948). It seems probable that it did in fact take the subjects about this length of time at *all* speeds to recognize a change of direction in the movement of the target-pointer and to initiate the appropriate change of direction in their own, and that the reason why a shorter time-lag occurred at the lower speeds was because the rate of swing of the 'target' pointer was sufficiently slow for the subjects to 'make up time' a little during each swing.

Discussion of the results

Looking over the results it is clear that the four measures we have described do not agree in the picture they present of the differences between our older and younger subjects. The scores for distance moved and for time-lag indicate that the older subjects' performance tended to break down at a lower speed than that of the younger. The scores for reversals of direction show no breakdown at any speed for either age-range. The scores for overall misalignment indicate that above the lowest speed the older subjects were about as accurate as the younger.

The discrepancy between the scores for reversals of direction and those for distance and time-lag presents no problem because these scores are for different aspects of the performance, and it is understandable that one aspect should show breakdown while another does

not. The striking conflict is between the scores for distance and time-lag, and the scores for overall misalignment. It is, however, fairly certain that this anomaly is due to the character of the overall misalignment scores. When the phase-lag exceeds 90 degrees the courses of the

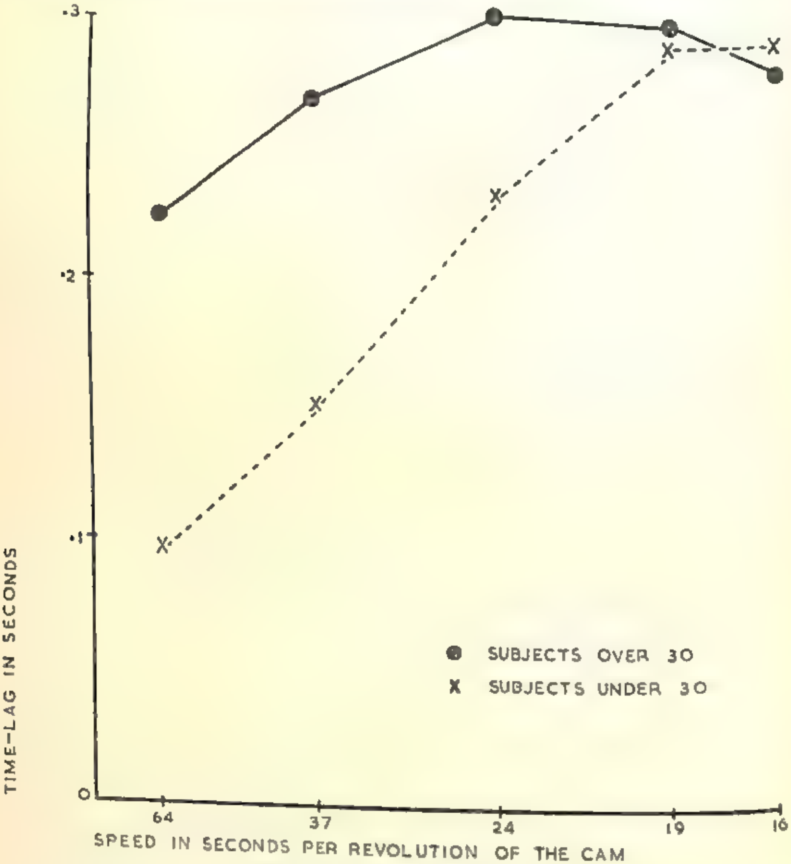

FIG. 5.4. Average time-lag

The older subjects had a substantially longer time-lag than the younger at the lower and middle speeds. The time-lags of both age-ranges rose to a maximum of a little under 0·3 second.

two pointers are so far out of step that the score for misalignment will actually be *lower* if the subject merely holds his pointer stationary in a central position than if he makes an attempt to track. If he does attempt to track he will minimize his misalignment score by tracking with a low amplitude of swing. It is unlikely, however, that this fact

was consciously realized by the subjects. After the experiment they were all asked whether, if they had to teach someone else to do this task, they would be able to offer him any advice about method. Their replies to this and other questions never gave the slightest hint that they had recognized the advantage of tracking with a low amplitude at the high speeds—indeed, hardly any subjects could formulate their methods in any way.

In seeking to explain the breakdown of performance at the high speeds and the earlier breakdown among the older subjects, it is noteworthy that the number of reversals made by the target-pointer, at the highest speed at which the younger subjects maintained amplitude and a phase-lag of less than 90 degrees, was about 100 per minute. At this rate the average swing of the target-pointer took about 0·6 second, which means that a quarter of the total swings were taking about 0·5 second or less. When the *average* duration of swing was less than 0·5 second—as it was at the second highest speed—the performance of the younger subjects showed definite signs of breaking down.

It has been found by previous workers studying tracking-performance (e.g. Craik 1947, Vince 1948) that about half a second is the minimum interval between two discrete events which permits them both to be dealt with satisfactorily. When the interval is less than this, response to the second is delayed or the responses to both first and second may be in some way modified. It seems very possible, therefore, that the performance of our younger subjects was in some way being limited not by any peripheral effector function, but by the number of reversals of the target-pointer to which they could respond adequately. The word 'adequately' is, of course, to be stressed in this connexion because the number of reversals they actually made rose well above two per second at the highest speed.

If this explanation is true of the younger subjects and applies also to the older, it is clear that the number of discrete items per minute with which they could deal adequately was substantially lower. At the highest speed at which the older subjects maintained amplitude and showed a phase-angle of less than 90 degrees, the target-pointer was reversing direction about 65 times per minute, so that the average duration of swing was a little over 0·9 second and the shorter swings a little under 0·7 second. When the *average* duration of swing was less than 0·7 second—i.e. at the middle speed—the older subjects' performances were showing signs of breakdown. If, therefore, we take the view that the younger subjects required a minimum interval of

about half a second between reversals of the target-pointer to maintain adequate tracking, it seems that the corresponding figure for older subjects was a little under 0·7 second.

Some support for this view is obtained by comparing the time-intervals between discrete events apparently required by the younger and older subjects with the *numbers of discrete movements* made by the corresponding age-ranges in the figure-tracing experiment. There the subjects in their twenties made about 135 discrete movements per minute—i.e. an average of about 0·45 second per movement. The subjects over 30 made on the average about 90 discrete movements per minute—i.e. about 0·65 second per movement. The figures for 'items per minute' are a little higher than in the present experiment, probably because the pattern to be traced was clearly laid out before the subjects, which enabled them sometimes to group two or three movements together and perform them as a single 'item'. The closeness of the figures in the two experiments is, however, sufficiently striking to suggest that there was some common 'ceiling' on the number of items per minute with which the subjects could deal, and that this ceiling was lower for the older subjects than for the younger. In the figure-tracing task, where there was *pressure* but not constraint for speed, the subjects appeared to have worked up to this ceiling. In the present experiment, where there was constraint for speed, performance above this ceiling tended to be inadequate.

While the presence of such a ceiling would account for the speeds at which performance in the present experiment broke down, it cannot in itself account for the form of the breakdown. Previous work on tracking suggests that the upper limit on the number of items that can be dealt with in a given time is largely due to three factors:

(*a*) The time required to perceive a stimulus such as a change in the direction of swing in the target-pointer, and to initiate the appropriate action—in other words, the *reaction-time*.

(*b*) The time required to make the necessary movement of the handle—i.e. the *movement-time*.

(*c*) The fact that a response once initiated has to go on for a finite period before it can be arrested or modified. In other words, once a response has been initiated the central mechanism goes, for a fraction of a second, into a *refractory phase* during which nothing fresh can be done. As a result, tracking consists of a

series of discrete stimulus-response units, although the movements may run smoothly into one another and not be distinguishable as separate (see Craik 1947, Hick 1948, Telford 1931, Vince 1948).

We will deal with each of these factors in turn:

(*a*) *Reaction-time.* A higher reaction-time among our older subjects would be in line with the findings of several of our other experiments, but at first sight runs clean counter to the present results:

(i) The mean time-lags shown in Fig. 5.4 were about equal for both younger and older subjects at the high speeds.

(ii) Reaction-time acting alone would not lead to a reduction in the amplitude of swing.

Neither of these objections rules out the possibility that our older subjects tended to have longer reaction-times than our younger, but they mean that if such longer reaction-times were operating their effects were indirect. For instance, some changes in the method of performance may have occurred which kept the *mean time-lag* constant in spite of an increase in the reaction-time.

(*b*) *Movement-time.* Mean velocity clearly was not setting limits to the performance. The highest average distances covered per minute by the subjects' hands were, for the younger subjects, about 340 cm., and for the older, about 260 cm.—i.e. obviously trivial amounts.

It must be remembered, however, that the *maximum* velocity attained must have been very much higher than the mean velocity, and it may be that this or some other essentially effector function, such as maximum rates of acceleration and deceleration, was setting limits to the amount of movement of the subjects' arms. The velocities likely to have been involved make this explanation improbable, but the possibility remains. Its truth or falsity could, however, be settled with fair certainty by supplementary experiments, and we intend to undertake these when opportunity occurs.

(*c*) *Refractory phase.* One important effect of this is that each movement of the subject's pointer has to be made with reference not only to the position of the target-pointer at the time, but to the position it will occupy a fraction of a second later. It is obvious that in a tracking-task where the movements of the target are irregular, this prediction cannot be made with certainty. Probably the best the subject can do, especially if his lag due to reaction-time is substantial, is to make a series of short movements which will be adequate to match the

shorter swings of the target-pointer, and will give him the opportunity when longer swings occur of 'catching the target on the way back'. This procedure will clearly lead to a substantial reduction in the total amplitude of movement, and will also tend to reduce the mean phase-lag.

The difficulty of prediction was very apparent to the author when he tried the task himself, and appeared to him to be of crucial importance in cutting down amplitude of movement at the higher speeds. He found himself unwilling—perhaps it would be more accurate to say *unable*—to commit himself to large or rapid movements of the lever because these would often have led to the subject's pointer swinging too far. Instead he quickly found himself making only small movements which, although sufficient to match the shorter swings of the target-pointer, were inadequate to match the longer. It is to be emphasized that this tendency was quite automatic and that it was a matter of extreme difficulty by conscious effort to adopt any other manner of performance.

If an explanation of our results along these lines is correct, it means that our subjects' performances above breakdown-speed are another example of a compensatory change of method in the face of difficulty, which tends to keep achievement constant. When the combined effects of reaction-time and refractory phase were such as to make anything like accurate tracking impossible, the subjects adopted, albeit unconsciously, the best procedure open to them. They maintained the semblance of tracking by making the correct number of reversals of direction, but lowered the amplitude of swing, thus keeping the total misalignment and mean time-lag at a minimum.

In concluding this chapter we may summarize four points which stand out clearly from the experiments we have described:

1. In all five experiments, changes associated with age appeared in one or more aspects of the performance, but other aspects were relatively unaffected.
2. Many of the changes of performance associated with age appeared to be of a compensatory nature—a deterioration in one aspect being partly balanced by an improvement or a change in another. As a result the overall achievement remained relatively stable, although there were considerable changes in the method whereby it was attained.
3. In Experiments 2, 4, and 5, and probably in the others as well,

the changes of performance with age appeared to be due to changes in the central rather than the peripheral mechanisms—it seemed clear that it was not the sense-organs or the muscles that were limiting the performances.

4. Although in all the experiments the changes with age were shown in the effector actions of the subjects, it seemed that in the first three, and possibly in the others as well, they were to be located in the central *receptor* mechanisms dealing with the organization of the incoming data, rather than in the *effector* mechanisms themselves.

We shall defer further discussion of these points until the end of the next chapter; meanwhile we may note one important point of technique. If we had been content to take for each experiment a single score of 'overall' performance, or to score only one aspect of the performance, we should have obtained results which would in every case have given a very incomplete picture of what the subjects were doing. Indeed, in the tracking experiment, we have a striking illustration of how a score for overall achievement may be highly misleading if it is unsupported by measures indicating how this achievement was attained. The view which we would have taken of the difference between the older and younger subjects' performances in this experiment, on the basis of the score for total misalignment alone, would have been very different from that indicated when the scores for movement and time-lag are also considered. This separate measuring of various aspects of a performance, as well as taking a total score, is a technique which would seem to be of very great importance not only in studies of ageing, but in all studies of complex skill.

VI

EXPERIMENTAL RESULTS

II. EXPERIMENTS ON 'MENTAL' SKILLS, AND GENERAL DISCUSSION

It is with some diffidence that we have divided the experiments in this chapter from those in the last. All skilled performance is in some sense a 'mental' skill, and it would seem that almost all skills involve some kind of co-ordinated overt activity by hands, organs of speech, or other effector organs. In the experiments in the last chapter these overt activities clearly formed an essential part of the skill, and without them there would not have been an experimental task at all. This cannot, however, be said of the experiments in the present chapter. In these the overt actions were largely incidental, and rather served to give expression to the skill than formed an essential part of it.

We would emphasize, however, that this distinction is difficult to maintain in any absolute sense, and that the two classes of skill shade into one another. It seems clear that the concepts we have outlined in Chapter III can and should be applied equally to both. Any distinction is more in the relative stress upon one or other aspect of skill in the tasks concerned, and the dividing-line is at least arbitrary and probably artificial.

Experiment 6

AN EXPERIMENT ON LOGICAL THINKING

The foregoing experiments throw doubt on the adequacy of a peripheral explanation of the changes associated with age in performance of skilled tasks. The nature of the displays presented, however, and of the actions required were such that the effects of any peripheral changes were mixed up with those of any central factors in a way which makes it difficult to separate the two with certainty.

Clearer evidence for central changes associated with age is found in the rather general finding that intelligence-test scores fall from the twenties onwards. It is true that some motor component is involved in writing down the answers to the items of an intelligence-test, and that some peripheral factors may be involved in reading them. These are, however, unlikely to influence performance to any great extent

unless major defects are involved, and in any case their influence would seem to be reduced to negligible proportions when the tests are conducted without time-limit. Because the falling away with age noticed with speeded tests (e.g. Miles and Miles 1932) has been demonstrated also with unspeeded tests (e.g. Foulds and Raven 1948, Raven 1948), it would seem clearly to be due to some central mechanism, and not to any important extent to peripheral mechanisms.

It should be noticed that most of the intelligence-tests used for the study of ageing have been of the type demanding selection of answers from among a number given with each item or set of items, and have not required the subjects to construct answers of their own. Any deterioration of performance must therefore be located in the ability to deal with the *problems presented* rather than with the construction of answers to them.

The comprehension of data in a problem and the putting of these together to produce a meaningful whole involve processes which appear to be similar to those described in Chapter III as leading to a 'perceptual response', and are thus essentially processes of *receptor organization.* The corresponding effector action would seem to be the formulating of an answer to the problem after it has been solved. If this analysis is valid, it is clear that the task in intelligence-tests which demand the selection but not the construction of answers is primarily one which concerns the receptor side. Such tests may in this sense be regarded as comparable with a skilled performance task presenting the subject with a complex perceptual display but requiring only a simple effector response.

At the beginning of our work we aimed at giving all our subjects an intelligence-test as well as taking measures of their performance on experiments. The difficulty of getting older subjects made it necessary to abandon this part of our procedure, but the results from the few subjects we did obtain confirm the general finding. The test we selected was Dr. Alice W. Heim's A.H.4 (see Heim 1947), a test designed for use with adults, which incorporates verbal, numerical, and spatial items in a pencil-and-paper form which can be given in a combined speeded and unspeeded manner. The verbal and spatial items are of the usual type requiring selection of one answer from a number given. The numerical items require the subject to construct his own answer.

Comparing our older subjects (over 30) with younger subjects (under 30) whose educational backgrounds were similar, we found

that the older subjects showed a marked falling-off in the number of items they completed within the time-limits allowed, especially in the case of the spatial items; but, when the subjects were allowed to complete the test without time-limit, the older subjects were quite capable of doing so although the items got progressively harder towards the end of the test.* The older subjects, however, made more errors on all the types of items than did the younger, so it would seem clear that both in speed and accuracy their performance showed a considerable deterioration.

We do not wish to lay any stress upon these small-scale results, but mention them by way of preface to the present experiment on logical thinking. As we have said, intelligence-tests, although they indicate fairly conclusively that an important locus of the fall in performance with age lies within the central mechanisms, furnish little evidence of whether this fall is due to some general deficiency, or whether some aspects of central activity are more affected than others, because the task they set is for the most part essentially one of dealing with data on the receptor side and the effector task is relatively easy. The fact that the subjects we tested with A.H.4 did not make a greater number of mistakes over the questions to which they had to construct their answers than over the questions for which answers merely had to be selected, cannot be regarded as satisfactory evidence that the deterioration of performance is essentially concerned with the receptor side, because the former class of questions were all numerical, and the latter all verbal or spatial, so that type of question was confounded with type of answer required. In the present experiment an attempt was made to overcome this ambiguity by giving material to which somewhat elaborate answers had to be constructed entirely by the subjects themselves. The task was thus in a sense analogous to a skilled performance task involving both a complex perceptual display and a complex effector response.

Material used

Each subject was presented with a series of statements between which there were certain connexions or inconsistencies according to the rules of formal logic, and was required to draw deductions from or point out fallacies in them. The subject was thus required, on the receptor side, to read and comprehend a series of statements and to realize the logical relationships between them. On the effector side his

* We have not made significance tests of these results.

task was to construct a written answer expressing the results of his 'receptor response' to the material. Two of the four sets used are shown below:

Set B

1. A right action is an action that will bring about at least as much good, or, failing that, will avoid at least as much evil as any other action open to the agent at the moment of acting.

2. A good man is a man who always does what seems to him, after due consideration, to be right.

3. It is always wrong to tell a lie or to break a promise.

4. Suffering in itself is undoubtedly evil.

5. In some cases it seems obvious that the only consequence of telling the truth or of keeping a promise will be to cause more suffering than would result from the opposite behaviour.

Instructions

Read carefully the statements printed on the sheet and answer the following questions.

Questions

(i) Are these statements compatible one with another?

(ii) If not, what is the least number that must be rejected to yield a completely consistent set?

(iii) Write out such a list, containing the fewest possible rejections, and state briefly wherein lies the incompatibility between those you reject and those you retain.

Set C

1. The diversion of labour to the production of machinery and other forms of capital goods is an essential step in the industrialization of a non-industrial country and must cause a temporary fall in the standard of living of the labouring classes of the country concerned.

2. People who are not familiar with an industrial economic system will never voluntarily submit to a reduction in their standard of living simply on the promise of better things to come.

3. There are only two ways of surmounting this obstacle in the path of industrialization: (i) by borrowing from abroad in order to keep up the standard of living at home; (ii) by making illegal the forming of trade unions and strikes and so making the workers wholly subject to the heads of industry.

4. Only after industrialization had advanced to a high level of efficiency in various parts of the world was it possible to adopt the expedient of borrowing.

5. No Communistic government wishing to industrialize can hope to obtain such loans.

Instructions

Using the facts stated on the sheet, state any conclusion or conclusions that you think are justified by them and explain briefly how your conclusion or conclusions follow from the facts.

When designing the statements and the method of the experiment, an attempt was made to overcome two additional criticisms levelled against studies of ageing using intelligence-tests: (i) that the test-items are of such a nature that older people regard them as trivial and not worth serious effort, and (ii) that they bear a resemblance to certain tests and examinations given in schools, and therefore discriminate against subjects in proportion to the length of time since they have left school. This second objection has more force in America than in this country because school examinations of the 'quiz' type are commoner there than they are here. It was hoped that the type of subject-matter and the controversial nature of the statements used in this experiment would ensure that they both engaged the interest of the subjects, and would not give any advantage to younger subjects by reason of their resemblance to the type of material dealt with in school.

Subjects and procedure

The 142 subjects were obtained from university extramural classes and from among and through friends and acquaintances of members of the Unit. They were for purposes of comparison arbitrarily divided into two groups: 75 subjects under 35 years of age (mean age 24·8), and 67 subjects over 35 (mean age 49).

Each subject was given one of the four sets of statements. The mode of presentation was to hand the statements to the subjects, together with the written instructions, stating that they were to answer in their own time. In view of the nature of the material it was pointed out that they were not required to append their names to their answers. The answer-sheets were returned to the experimenter a few days later either by the subjects in person or through the post.

Results

The clearest finding that emerged from the results was that, although the older subjects seemed as capable as the younger of giving answers *of some sort* to the problems, they did so in a different way. In particular, the older subjects tended not to draw logical deductions based strictly on the statements as given, but to introduce supplementary premisses or to confine themselves to comments upon the statements. The presence or absence in the replies of deductions drawn in the manner required by the instructions and free from confusion by additional premisses or comments about the material was

a criterion on which an unambiguous classification of the replies could be made. We quote by way of illustration some examples of each type.

Examples of answers in which the required deductions were drawn are:

Schoolteacher, aged 32, in answer to question (iii) of set B—

According to statement 5 a lie would in given circumstances cause less suffering, therefore (statement 4) would be less evil than the truth, and would (statement 1) be a right action. Under these circumstances a good man in doing right would tell a lie. As statement 3 states that it is always wrong to tell a lie it must be rejected.

Housewife, aged 45, in answer to question (iii) of set B—

Statements 1, 2, 4, and 5 on the question sheet are compatible with each other, but 3 must be rejected because if a case arises such as that in statement 5, surely a good man as qualified in 2, will not tell the truth or hesitate to break a promise, because to do so would cause unnecessary suffering (4), and being a good man he naturally wishes to carry out statement (1).

Clerk, aged 34, in answer to set C—

The first conclusion justified from the facts stated is that, while a non-Communist state would meet no insuperable obstacle in the path of industrialization, it would be impossible for a Communistic state to become industrialized. The fact that people unaccustomed to an industrial economic system would not accept a reduction in their standard of living, necessary to achieve industrialization, can only be surmounted in two ways. These are both open to a non-Communistic state, provided a sufficient amount of industrialization has occurred in other parts of the world to permit of a loan. A Communistic state would be unable to effect such a loan, however, and is thus faced with the alternative of suppressing trade unions and strikes and making the workers subservient to the heads of industry, which is incompatible with Communistic doctrines. If it adopted this course it would cease to be a Communist state.

A second conclusion is that the first states to become industrialized must have done so by a policy of repression as, with no other states industrialized, loans were impossible.

Examples of answers of the purely commenting type are:

Extramural lecturer, aged 46, in answer to question (iii) of set B. (The subject rejected statements 1, 2, and 4 in answer to question (ii).)

The rightness or wrongness of an action must, as I think, be determined by its end-result. Thus a good man is the one who does what is right according to the light he possesses. Experience has taught me that to adhere absolutely to the truth or even to a promise may lead to suffering—personal suffering, and moreover suffering to other people. This is contained in statement 5. Regarding 4, I might add that suffering is evil, though in some cases it may be a form of discipline which can result in

some kind of good. Even so, I find it difficult to justify it. I am forced to regard it as an evil which ought to be eradicated.

Industrial welfare officer, aged 49, in answer to set C—

Regarding paras. 1 and 2, people will not co-operate unless they are educated to appreciate (1) the actual position as it applies to the individual and the action as a whole; (2) unless the leaders are quite frank and can be trusted to give them a square deal, before, during, and after a national crisis.

There must be an incentive to work, to regard work not as a painful necessity but as a pleasure, or a means of obtaining satisfaction unobtainable in any other way.

Regarding para. 3. (1) Borrowing from abroad is a short-term expedient which tends to confuse the issue, creates a wrong impression among the workers, and makes the borrower subject to the financial dictatorship of the country lending the money, restricts the market and leads to a state of distrust, &c. (2) The making illegal of trade unions and strikes is the best way to foment unrest, workers suffering from frustration will find an alternative outlet for their emotions, will not co-operate with the heads of industry, and will listen to the worst if it offers some redress for their suppressed opinions.

Regarding para. 4. 'Borrowing' as we now understand it only becomes possible when the majority of the major countries have adopted a monetary standard. 'Bartering' has been in universal practice ever since history has been recorded, and no doubt existed before.

Regarding para. 5. Communistic governments had and do obtain loans.

TABLE 6.1. *Classification of subjects into those who drew deductions from and those who commented upon the material*

Set	*Age-range*	*Subjects who drew deductions*	*Subjects who made comments only*
A	Under 35	10	6
	Over 35	1	9
B	Under 35	13	6
	Over 35	3	18
C	Under 35	25	4
	Over 35	13	15
D	Under 35	5	6
	Over 35	..	8

The older subjects showed a greater tendency to make comments instead of drawing deductions than did the younger.

The figures obtained by classifying the replies into those in which deductions were drawn from the material as the instructions required and those which consisted solely of comments about the material are set out in Table 6.1. Those in which both deductions were drawn and

additional comments occurred were placed in the former class, provided the comments did not lead to confusion of the argument by additional premisses.

The figures in this table show a substantial association between age and failure to make the required deductions for each of the four sets of statements used; this association is significant in each case except the fourth (where the number of subjects was small).

Discussion of the results

In seeking to explain the failure of the older subjects to make deductions in the required manner a number of widely different possibilities need to be considered. We will deal with what seem to be the most important of these in turn:

1. Examination of the occupations of our subjects suggested that the younger tended to be of occupational grades making somewhat higher intellectual demands than those to which most of the older subjects belonged. It is reasonable to expect that the drawing of deductions would go with an occupational grade which is high in this respect, and it seemed possible that the difference in the type of answers given by our older subjects might, therefore, be due to this and not to age as such. The subjects were accordingly divided into three occupational grades, thus:

I. University teaching and research.

II. Professional and managerial.

III. Clerical, secretarial, &c.

The distribution of our subjects among these grades is shown in the third column of Table 6.2. In the fourth and fifth columns of this table, the numbers of subjects drawing the required deductions and the numbers of subjects making comments only are shown for each occupational grade separately. It will be seen that the association between age and the tendency to comment on the material rather than draw deductions was present in each of the three grades, although it was significant only in grade II. It seems clear that the difference of occupational grade associated with age in our subjects does not provide a sufficient explanation of the tendency for the older subjects to fail to carry out the experimental task as set.

2. In view of the opinion frequently voiced that the tasks set in some previous studies of ageing have failed to engage the interest of older people, and of the likelihood that our older subjects were busier

in their everyday lives than were our younger, we examined the possibility that the failure of our older subjects to draw deductions was due to carelessness or unwillingness to take trouble over the experiment.

TABLE 6.2. *Relationships between age, occupational grade, and drawing deductions from the material*

All four sets combined

Occupational grade	*Age-range*	*No. in age-range*	*Subjects who drew deductions*	*Subjects who made comments only*
I	Under 35	35	26	9
	Over 35	18	8	10
II	Under 35	35	24	11
	Over 35	35	8	27
III	Under 35	5	1	4
	Over 35	14	1	13

The older subjects of each occupational grade showed a greater tendency to make comments instead of drawing deductions than did the younger subjects in the same grade.

It may be said at once that there was no evidence of perfunctoriness or carelessness in the answers, and that remarks made by many of the subjects confirmed that they were by no means indifferent to the task. As an additional check, however, the *mean lengths of answer* were calculated. It seemed likely that if the older subjects were not interested in the task they would tend to produce shorter answers. The figures obtained for each of the four sets of statements are set out in Table 6.3, from which it will be seen that there was clearly no significant tendency for the older subjects to produce shorter answers than the younger. The only set in which there was a marked difference between the age-ranges is B, in which it was the older subjects who, on the average, produced the longer answers.

TABLE 6.3. *Numbers of words in answers*

Set	*Subjects under 35*	*Subjects over 35*
A	209	184
B	147	198
C	102	94
D	190	197

The figures provide no evidence of a decrease in the length of answers by the subjects over 35.

3. It seemed conceivable (although unlikely) that a number of our subjects who failed to draw the required deductions *misunderstood the instructions* given on the papers. This, however, clearly cannot give a sufficient explanation of our results. Not only would the number of subjects who had misunderstood the instructions be improbably large, but several subjects in their answers gave definite evidence that they had understood the instructions but found it difficult to carry them out, e.g. a schoolteacher, aged 57, commenting on C:

> 'I find this work difficult because I am inclined to question several of the statements, instead of accepting them and drawing the conclusions, if any, which may be justly derived from them.'

It should be pointed out that, even if misunderstanding of the instructions had been a partial cause of the age-differences observed, its status as an explanation could not be more than an intermediate one. Misunderstanding of instructions would seem necessarily the result of either

(*a*) the over-potency of some pre-formed 'set' or attitude with which the subject approached the instructions, and which caused him to give them a meaning other than that intended by the experimenter and conveyed to subjects lacking such an attitude, or

(*b*) some failure to obtain meaning out of the instructions because of a failure of comprehension.

In either case misunderstanding of instructions would become a special case of the possibilities we discuss below, and may therefore be taken with them.

4. The comments made by the subjects about the statements represented essentially the application to the material of knowledge and opinions which they brought with them to the experimental situation. It looked as if the older subjects were increasingly using these in dealing with the material, and were in a sense unable to get away from them to a more strictly logical treatment. Many of them who were given credit for having answered correctly, inserted one or two comments obviously deriving from opinions or knowledge in an answer which was otherwise strictly in the manner required by the instructions. Many, however—such as the subject who produced the second of the commenting types of statement, quoted on p. 90—seemed to make no attempt to deal with the matter as a whole, and no attempt to

draw any conclusions from the statements; all that their answers contained were disconnected remarks about the individual statements in which the writers gave information and expressed their views.

The question remains, however, as to how far this kind of treatment of the material resulted from

(*a*) *interference* with thinking coming from the firmer, better-structured opinions and greater information that experience, increasing with age, brings with it, and how far

(*b*) it represented some form of secondary effect of an *inability to organize complex material* in a logical manner.

It must be remembered that in one sense the commenting type of answer given by the older subjects is 'better' than that demanded by the instructions. The data are not dealt with as isolated units devoid of meaning and associations beyond themselves, but are dealt with as thoroughly meaningful and linked up with the rest of the subject's experience and knowledge. This procedure, although it may hamper the drawing of logical conclusions as such, is an obviously valuable method of dealing with many real-life situations, and is, therefore, likely to become habitual, and to be used even in situations where it is not suitable.

On the other hand, any *inability* to draw conclusions from the data, especially an inability which increases with age, is likely to give rise to the commenting type of response either

(i) as a compensatory mechanism enabling *some* response to be made to the data—presumably the best available in the circumstances; or

(ii) because the inability to deal with the material in the way demanded by the instructions results in a failure to control emotionally-toned opinions, which are thus left free to obtrude themselves in the answers.

Whether we regard intrusion and inability as separate explanations or whether we regard them as connected, the results of their action have the important feature in common that they resulted in a failure not of *response* in the sense of producing some kind of answer, but of *comprehending* or *organizing* the material presented. Thus it again appears in the present findings that the striking change which is associated with age is more one of receptor than of effector function.

Experiment 7

SOLVING ELECTRICAL PROBLEMS

A second problem-solving experiment of a different nature was undertaken not only to study the organization of data by different age-ranges in this kind of task, but primarily to investigate the effect of different training-methods on subsequent performance.

The apparatus for this experiment consisted of a number of small boxes, each with six terminals on top; these terminals were connected underneath by resistances of 1,000 ohms. The subject was given a box, together with a resistance-meter and a circuit-diagram which showed the connexions between the terminals in the box but did not indicate which of the terminals shown in the diagram corresponded to each of the terminals on the box. The subject's task was to deduce which terminals corresponded to which by means of readings taken on the resistance-meter. The apparatus and experimental method were designed to enable a detailed record to be made of the procedure followed in arriving at a solution of the problem, but unfortunately did not permit the recording of the exact time taken over different parts of this procedure.

The task simulated the problems involved in fault-finding by radio and electrical service-engineers. It was derived from one developed by Dr. A. Carpenter (see Carpenter 1946), who found that, in the more complex form in which he used it, performance correlated fairly highly with scores for the intelligence-test A.H.4. Both this task and the intelligence-test involved the organization of, and deduction from, somewhat complex data, but the former differed from the latter in requiring the subject to construct, instead of merely select, his response. It differed also from the logical-thinking experiment in that, when the problem had been successfully solved, the solution could be checked for accuracy.

The usual method of dealing with the problem was to take readings on the meter until one or two of the easier terminals had been identified, then to use the information thus gained as a guide in taking further readings which would identify another terminal, and so on. The procedure was thus truly serial in the sense in which we have used the term in Chapter III, because the solution at each stage 'grew out of' the solution of the previous stages.

The experiment consisted of an initial training-period in which one box was used, followed by a 'test' period in which four boxes had to be

solved. The circuit-diagram of all five boxes was the same, but the arrangement of the terminals was different in each case. The circuit is given in Fig. 7.1.

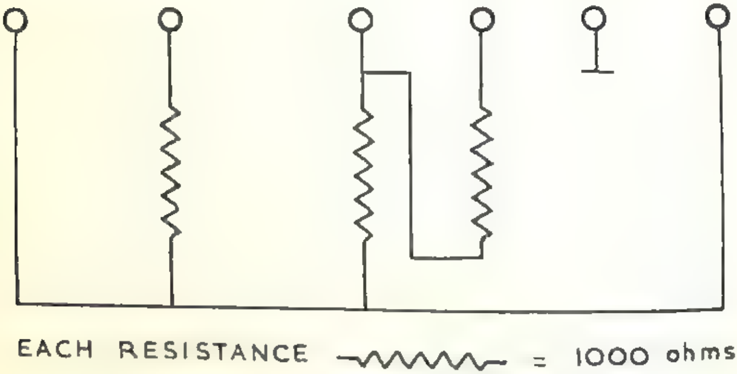

FIG. 7.1. Circuit-diagram of the boxes

The subjects were divided into two age-ranges—23 above and 29 below 30, with mean ages 45·9 and 20·1 respectively. The younger subjects consisted of naval ratings and students, and the older of university teachers and research workers, army personnel, and some friends and acquaintances of members of the Unit who varied widely in occupational status. In obtaining subjects care was taken to avoid those who had previous knowledge of electrical or radio work. The subjects in each age-range were divided into four groups, and each group was given a different type of instruction during the training period:

(*a*) The experimenter *demonstrated* the essential *general* principles involved in solving the boxes, but without indicating the detailed solution of the particular box.

(*b*) The experimenter gave a *specific* and detailed *demonstration* of how to solve the particular training-box according to 'rule of thumb' without indicating general principles.

(*c*) The subject was given the *general principles* required to solve the boxes in the form of *written instructions* with examples.

(*d*) The subject was given *specific written instructions* stating in detail how to solve the particular training-box.

It will thus be seen that two groups obtained general and two obtained specific training, and that of each of these pairs one obtained its training in the form of a demonstration, and the other through the medium of written instructions.

Results

Differences between age-ranges in solving the problems. Some subjects failed to solve the first box presented, i.e. were unable to do the task at all within the experimental situation. The proportion who so failed was about the same in both the age-ranges—8 (28 per cent.) in the younger range and 5 (22 per cent.) in the older. The similarity of these two percentages cannot, however, be taken to indicate that older subjects in general are as likely to be able to solve these problems as are younger. The older subjects were on the average probably of a somewhat higher intellectual level than the younger, and their achievements relative to those of the younger subjects were probably greater than they would have been had the two age-ranges been properly matched.

The data obtained in this experiment do, however, permit an important type of comparison between older and younger which is rather different from the usual comparison of matched representative samples. The subjects in the two age-ranges who completed all the four boxes in the 'test' part of the experiment provide two groups who show in an important sense *equal achievement*, and by comparing them we are able to compare the manner in which an older and a younger group *attain the same achievement*.

The measurements of performance taken in the experiment enable such comparison to be made in three respects—number of terminals correctly identified, time required to produce a solution, and number of meter-readings taken. The figures for these measures are shown in Table 7.1, together with the actual and percentage differences between the two age-ranges. The percentage differences are also shown graphically in Fig. 7.2.

It will be seen from the table and figure that:

(*a*) In *accuracy*, the two age-ranges were closely similar. The older subjects tended to be a little less accurate in solving the first box and a little more accurate over the subsequent ones, but the differences were small and not significant. It appears, therefore, that on this criterion, as well as on that of ability to do the task

at all, we are dealing with two groups whose achievements were approximately equal.

TABLE 7.1. *Comparison of measures (means per subject) for older and younger subjects in electrical-problem experiment*

	Age-range	Boxes 1st	2nd	3rd	4th
Terminals correctly identified	Younger	5·61	4·59	5·38	5·63
	Older	5·08	4·92	5·55	5·95
Difference: older minus younger . . .		−0·53	+0·33	+0·17	+0·32
Difference: as % of mean of younger .		−10%	+7%	+3%	+6%
Time taken (*in seconds*)	Younger	253	260	117	125
	Older	465	418	254	227
Difference: older minus younger . . .		+212	+158	+137	+102
Difference: as % of mean of younger .		+84%	+61%	+117%	+82%
Readings taken on meter	Younger	20·4	27·0	14·2	17·8
	Older	28·4	34·4	20·0	22·8
Difference: older minus younger . . .		+8·0	+7·4	+5·8	+5·0
Difference: as % of mean of younger .		+39%	+27%	+41%	+28%

The younger and older subjects were very similar as regards accuracy, but the older took more readings on the meter, and very much longer time.

(*b*) The older subjects, however, took on the average markedly longer *time* to solve the boxes—more than half as long again as the younger in all four cases. Unfortunately the objective scores were not sufficiently detailed to show how this extra time was spent, but observations made of the subjects at work indicated that it was spent mainly on interpreting the readings. The actual taking of readings, and the writing of the numbers of the box-terminals against the terminals shown on the circuit-diagram, took very little time.

(*c*) The older subjects took, on the average, substantially more *readings on the meter* than the younger, although the difference between the age-ranges was less than in the case of time. This means that the older subjects not only took more readings but longer time per reading than the younger.

Considering the results for accuracy, time, and meter-readings together, it appears that while the older subjects were able to solve the problems, the organization of the data required to do this caused them greater difficulty than it caused the younger.

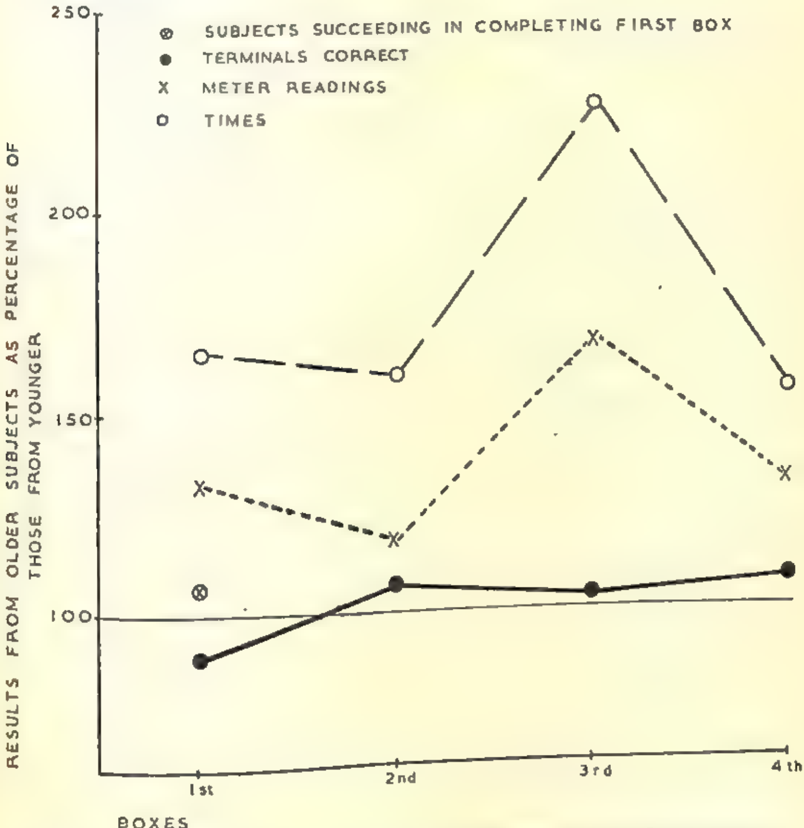

FIG. 7.2. Results from older subjects as percentage of those from younger There were no substantial differences between the two age-ranges in the number of subjects completing the first box or in the numbers of terminals correctly identified. The older subjects, however, took a longer time and required more meter-readings.

The effects of different training-methods. Differences of *time* and *meter-readings* between the various training-methods were small and insignificant. There seemed, however, a fairly clear indication that training-method had an effect, which varied between the younger and older subjects, upon the ability to produce an accurate solution of the first box. From Table 7.2, it will be seen that the older subjects made

more errors than the younger when training had been by demonstration, and slightly fewer when the training had been by written instructions.

TABLE 7.2. *Relationships between training-method, accuracy, and age-range, for the first box*

	Number of terminals correctly identified						
	0	*1*	*2*	*3*	*4*	*5*	*6*
Training by demonstration							
Number of subjects attaining each level of accuracy:							
Younger	..	..	..	1	..	3	10
Older	3	..	..	4	..	1	5
Training by written instructions							
Number of subjects attaining each level of accuracy:							
Younger	6	1	1	..	..	2	5
Older	1	1	1	1	..	1	5

The younger were a little more accurate than the older when training had been by demonstration. The older were a little more accurate than the younger when training had been by written instructions.

We do not wish to lay much stress upon this result because the numbers of subjects involved were small, and it may very possibly have been due to the difference of occupational status between our age-ranges. We mention it, however, because it does link up very plausibly with the difference between the age-ranges in the number of meter-readings taken, as we discuss below.

Discussion of the results

In seeking reasons why the older subjects should have found it more difficult than the younger to solve these problems, two points appear to be important:

(*a*) the longer time taken by the older subjects over each meter-reading indicates that they were having difficulty in giving meaning to the readings, and

(*b*) the large number of readings taken by older subjects means that some readings were being taken more than once. This appeared to be largely due to readings being forgotten, several older subjects complaining that they 'could not hold the readings in their heads'.

It is probable that these two points are closely interdependent. The solution of a problem of the type used in this experiment appears to demand the bringing together of a quantity of information, some of which is used at any one moment while the rest is being 'carried' ready to be brought into play when required. Slowness in dealing with any part of the problem will place a strain upon the 'carrying' mechanism —perhaps we might say 'short-term memory'—and will cause pieces of information such as meter-readings to be forgotten so that they have to be taken again. On the other hand, any failure to carry information satisfactorily will have the effect of reducing the quantity of data that can be applied simultaneously to the part of the problem being dealt with, and at least slow down the solution if not prevent it altogether. It seems, therefore, that any slowness in organizing data will produce an apparent inefficiency of short-term memory, and any deficiency in short-time memory will impair the ability to organize data. How far each of these contributes to the kind of changes we observed in our older subjects is a question which would seem to merit further study.

From the learning point of view it is likely that a person who is even mildly deficient in either of these respects will find suitably written instructions superior to demonstration as a training-method, because they can be conned over several times, and if any detail is forgotten the subject is able to go back and recover it. When training is by demonstration, any detail not grasped or forgotten will be lost unless the subject asks to have the point gone over again. Because it tends to be embarrassing to have to do this frequently, an older subject trained by demonstration is likely to have a number of gaps in his grasp of the methods of solving the problem when he begins the test. The issues raised are clearly important, and we have undertaken further laboratory experiments on learning and remembering, and a field-study of training in industry. One of the experiments follows later in this chapter (Experiment 9). We hope to be able to report the rest at a future stage.

Experiment 8

AN INSPECTION TASK

From what has been said of the foregoing experiments, it might be expected that, in a repetitive task where the central organization required could be built up during the first few 'trials' and thereafter used more or less unchanged, older people would

(*a*) show a performance in some ways poorer than that of younger subjects at the beginning of the task; and that

(*b*) once they had become 'set', their performance would differ little from that of younger subjects.

Some confirmation of both these expectations was provided by the present experiment. We have not been able to try this experiment on as large a sample as we should have wished, but the main findings are of sufficient consistency for them to appear unlikely to be misleading.

The subject sat facing a screen from behind which a series of 60 rectangular aluminium blocks, 13 cm. in length and of various widths, appeared one at a time on a horizontal runway. The subject had to judge whether each block was 'up to standard' on two criteria:

(*a*) the width of the block—blocks greater or less than 6 cm. wide were to be rejected;

(*b*) the accuracy of a design of four holes one of which varied in position relatively to the others in some blocks—blocks in which this hole was not in the correct position were to be rejected.

The widths and 'pattern-errors' of the blocks used are set out in Table 8.1.

TABLE 8.1. *Widths and pattern-errors of blocks presented in each run*

Width of block in centimetres	*Number presented*
7·0	1
6·8	2
6·6	4
6·4	5
6·2	8
6·0 Correct	20
5·8	8
5·6	5
5·4	4
5·2	2
5·0	1

Pattern-errors			
Left		*Right*	
0·4 cm.	0·2 cm.	0·2 cm.	0·4 cm.
2	3	3	2

Examples of a block correct in both respects, of a block which was too narrow (5.2 cm. wide), and of a block showing an error of pattern, were displayed on the screen above the runway throughout the experiment. These were explained to the subject before the experiment began and he was told that no block would be wrong in more than one respect.

The subjects were required to indicate their acceptance or rejection of each block by pulling or pushing respectively a lever on the right-hand side of the apparatus. The words 'ACCEPT' and 'REJECT' were clearly marked in large white letters at the appropriate ends of the slot in which the lever moved. The movements of the lever and the appearance of each block on the runway were recorded on a paper strip moving over a constant-speed drum. This enabled the time elapsing between the appearance of a block and the recording of the subject's judgement to be measured. The subjects were instructed to press the lever back and forth to get its 'feel' before the experiment began.

The apparatus was arranged so that the blocks could be made to appear on the runway either at regular intervals from about 2 seconds upwards, or on each pressing of the lever—i.e. pressure on the lever registering judgement automatically caused the next block to appear. The experiment thus provided the subject with a twofold discrimination task, and enabled a detailed study to be made of the timing and accuracy of this discrimination under conditions where the speed was set either by the experimenter or by the subject.

The 57 subjects were divided into four age-ranges—8 over 65, 12 from 45 to 64, 12 from 25 to 44, and 25 under 25. Younger subjects were students, R.A.F. aircrew, and naval ratings; and older subjects were again recruited in such a manner as to provide groups of comparable status. Each subject was given the series of blocks three times, once at his own speed, once at 3 seconds per block, and once at 5 seconds. Half the subjects in each age-range had their first run at their own speed, half at 5 seconds per block.* The subjects under 25 had three further runs, but these could not be given to the higher age-ranges because most of the older subjects found this task—in contrast to others—intensely irritating. By the time they had completed the third run of 60 blocks very few of them could be persuaded to continue. Frequently they pleaded lack of time, but it was clear that this was an excuse as they had, before the experiment began, agreed to

* In the youngest age-range, 11 and 14 subjects respectively.

spend the time on it that was required by the full six runs (about 40 minutes).

Results of the experiment as a whole

A. *Accuracy of judgements.* When the experiment was first designed it was expected, on the ground that speed and accuracy were likely to be compensatory, that older subjects would show less accuracy when working at a speed determined by the experimenter than when allowed to work at their own speed. Inspection of the results did not, however, reveal any marked differences of performance between these two conditions—probably because the speeds were set too low to impose any great speed-pressure. Accordingly, for comparing the accuracy of the various age-ranges, the three runs have been combined.

The percentage of blocks of each width accepted by each of the four age-ranges during their three runs is shown in Fig. 8.1. Perfect discrimination would be represented by 100 per cent. acceptance of blocks of 6-cm. width and 0 per cent. acceptance of all others. Complete lack of discrimination would be represented by acceptance of an equal percentage of each width, the percentage depending on the balance between tendency to accept and tendency to reject. Between these two extremes good discrimination is indicated by a steeply rising, narrow curve, and poorer discrimination by a broader, flatter one.

Three points may be noted about the curves in Fig. 8.1:

1. Although there is some tendency for the curves to broaden with age, this is negligible until the highest age-range is reached, the slopes of the curves for the three younger age-ranges being closely similar. Very much the same relationships between the age-ranges were found in the case of pattern-discrimination, the curves for which have accordingly not been reproduced.
2. Blocks wider than the standard were more frequently accepted than blocks which were narrower—indeed the highest percentage for all age-ranges was above 6 cm. This tendency was probably due to a visual illusion or to a 'constancy-effect' due to the positioning of the standard block provided for comparison with the blocks to be judged and, although striking, is of little relevance to the present discussion.

3. The subjects over 65 showed a discrimination of the small blocks as good as that of the younger subjects, but accepted a strikingly

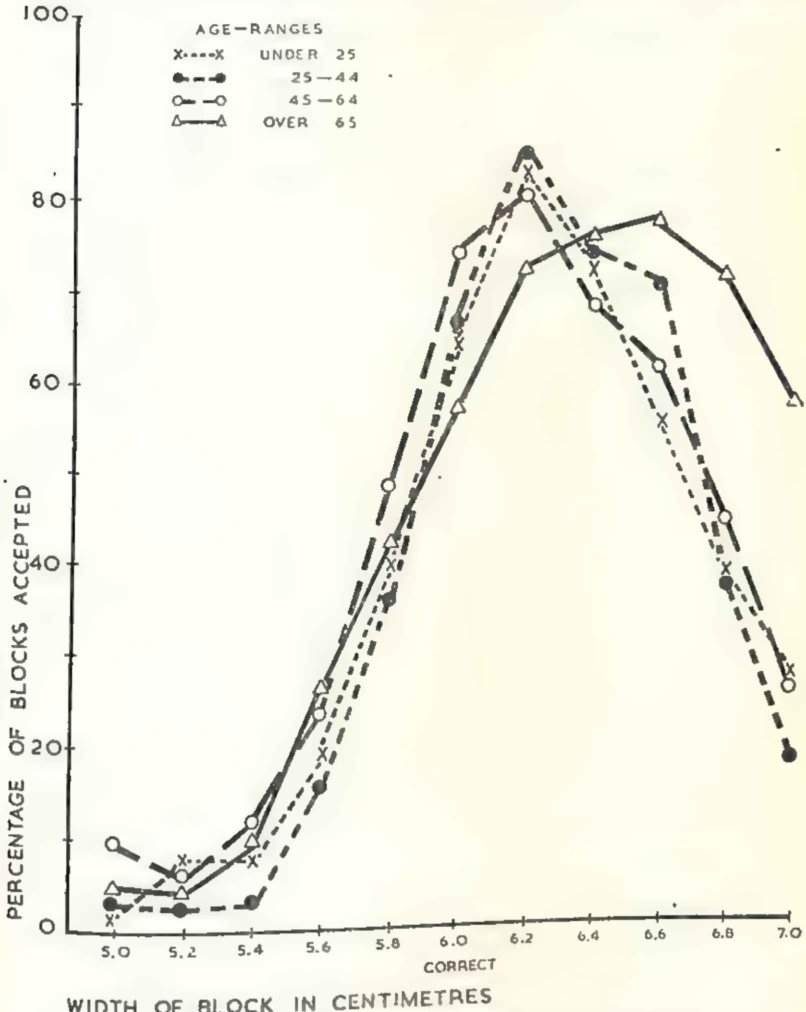

FIG. 8.1. Percentages of blocks accepted during first three runs
There was little consistent difference between the three age-ranges under 65. The subjects over 65, however, accepted many more large blocks than did the younger subjects.

greater proportion of very large blocks. Why they should have done this is not clear, but the difference of width between these very large blocks and the standard was obviously too great for

their acceptance to be due to defects of the peripheral visual mechanism. We thought at first that it might have been because the sample 'error-block' displayed on the screen in front of the subject was narrower than the standard, and that the older subjects had been forgetting the instructions and tending to reject only blocks which were too narrow. This explanation seems to be excluded, however, because we obtained the same result in a brief check experiment in which nine subjects over 65 were given one run at their own speed with a sample error-block much too wide (6·8 cm.) displayed on the screen.

B. *Time taken to record judgements*

(i) The mean times per run of sixty blocks for the runs at subject's own speed are set out in Table 8.2, from which it will be seen that, although there was some variation among the groups—notably the very long time taken by one of the groups over 65—there was no consistent slowing with age.

TABLE 8.2. *Mean judgement-times in seconds per subject per run presented at speed determined by the subject*

Age-range	*Under 25*	*25–44*	*45–64*	*Over 65*
Subjects for whom this run was their first	147	173	155	241
Subjects for whom this run was their second	105	108	126	99
Mean of the above	126	140	140	170

There was little evidence of any consistent slowing with age.

(ii) Times for runs at a speed determined by the machine are not listed for two reasons: first, it is not possible to work out satisfactory average figures for runs when cases occur in which the subject fails to respond to a block within the time-limit allowed, and second, even if such averages could be presented it would be difficult to give them meaning. It seemed clear when observing the subjects that under these conditions some of them tended to respond as quickly as possible, as when they were working at their own speed, but that others tended to delay giving their judgements until the time allowed was nearly over. Some idea of the adequacy of performance in terms of time taken may, however, be gained from the number of blocks to which no response was recorded in the time allowed. The figures for these are

shown in Table 8.3, from which it will be seen that the number was very small in the two younger age-ranges, a little higher in both the 45–64 groups, and substantially higher in both the groups over 65.

TABLE 8.3. *Mean number of times per subject per run that no judgement was recorded, when blocks were presented at a speed determined by the machine*

Age-range	*Under 25*	*25–44*	*45–64*	*Over 65*
Subjects whose first run was at their own speed	0·14	0·17	0·18	4·00
Subjects whose first run was at 5 seconds per block . . .	0·11	0	0·58	3·38

Over 45 there was a rise in the number of times that no judgement was recorded. The rise was slight in the 45–64 age-range, marked in the over-65 age-range.

From these results it seems clear that performance was well maintained among our subjects, at least as far as those in their early sixties, in spite of their irritation at the experimental task.

Results at the beginning of the experiment

Although it appeared that the performances of our subjects, except in the highest age-range, were very similar over the period of the experiment as a whole, their dealing with the first few blocks showed considerable differences associated with age. The mean times taken during their first run by the subjects for whom this run was at their own speed are shown in Fig. 8.2. It will be seen that the mean times for the first few blocks increased markedly with age. Thereafter the times of the over-65 range remained appreciably higher than the others, but the three younger ranges all took nearly equal times.

The results for subjects whose first run was at a speed determined by the experimenter cannot be presented as means because any block not responded to in the time allowed (5 seconds) was replaced by another, and when this happened the subject usually failed to record any response. If, however, these 'no response' cases are regarded as judgement-times of 'more than 5 seconds', the rank correlation between time and age-range is significant for the first and the second blocks and non-significant thereafter.

As regards accuracy, Table 8.4 shows that the older subjects whose first run was at their own speed were a little more accurate than the

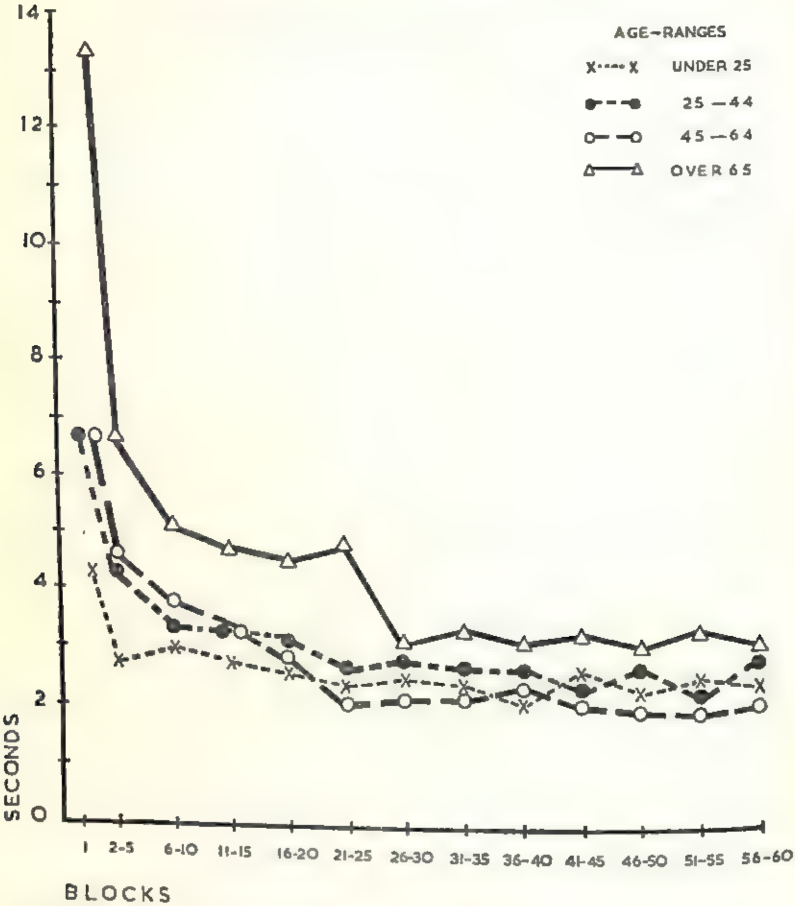

FIG. 8.2. Mean judgement-times per block during first run by subjects who did this at their own speed

The differences between the age-ranges were greater at the beginning than later in the run.

TABLE 8.4. *Mean number of blocks judged wrongly out of the first ten presented (per subject)*

Age-range	*Under 25*	*25–44*	*45–64*	*Over 65*
Blocks presented at subjects' own speed	4·4	3·8	3·0	3·0
Blocks presented at 5-second intervals	3·6	4·7	5·2	4·8

When the blocks were presented at the subjects' own speed, the accuracy tended to rise with age. When the blocks were presented at a speed determined by the machine, accuracy showed no consistent trend with age.

younger at judging the first ten blocks. Among the subjects whose first run was paced by the machine, accuracy tended to fall with age. Speed and accuracy thus tended to be compensatory, although the differences of accuracy involved were small.

Discussion of the results

We may summarize these findings by saying that our older subjects were markedly slower than our younger in dealing with the first few blocks. After the first few, however, the performance of the age-ranges below 65 became closely similar. The subjects over 65 remained very inaccurate, but as the experiment proceeded they attained speeds which were much closer to those of the younger than they had been at the beginning.

The slowness of the older subjects at the beginning of the experiment appeared to have resulted from two causes. To some extent it was due to extra caution—a tendency we have noted in other experiments, and reflected here in the attainment of slightly greater accuracy over the first few blocks. Much more, however, it seemed to have been due to an initial difficulty in comprehending the task. It was striking that with age there went an increased tendency to find difficulty in understanding the instructions. Older subjects often required the experimenter to go over the instructions more than once, and frequently rehearsed parts of them aloud before pronouncing themselves ready to proceed with the task. It could be seen when observing the subjects that this was due to a real difficulty in 'getting the task clear' and was not merely a sign of additional care and caution.

The lessening of differences between the age-ranges after the beginning of the experiment seems at first sight to run counter to the findings of our other experiments, because the series of blocks was very obviously a changing display—a feature which in the grid-matching and tracking experiments had been associated with marked changes of performance among older subjects. It appeared, however, from observing the subjects, that although the display changed objectively, the receptor 'organization' required to deal with it did not change. When making their first few judgements the subjects frequently looked at the sample blocks displayed on the screen in front of them. As the experiment proceeded they tended to refer to them less and less, seeming to 'carry the correct width in their heads'. In other words, they had, in the course of the first few judgements, built up a standard which could be applied immediately to each new

block as it came along. This appears to be a smaller-scale example of the tendencies noted among the older subjects in the logical-thinking experiment, who dealt with the material presented there in terms of pre-existing 'organizations' from past experience rather than by a fresh act of comprehension. The difference between the logical-thinking experiment and the present one is that in the former the pre-existing organizations applied to the material were brought by the subjects to the experiment and were *not* appropriate, while in the latter they were built during the experimental session and using them was the correct method of doing the task.

The observations of the subjects and the objective scores are together a very fair fulfilment of both the expectations mentioned at the beginning of the experiment, at any rate for the subjects under 65. The subjects over that age certainly showed the relatively poor initial performance which we expected, but they did not attain complete equality with the younger subjects as the experiment proceeded. They did, however, tend to equality, and it is possible that they would have reached it had the experiment gone on longer.

Experiment 9

A LEARNING TASK*

It seemed to us that if the difficulty of organizing incoming data shown by the older subjects in the foregoing experiments was true, there should be substantial changes with age in the performance of a task in which the main stress is laid on the learning of new material. Some kind of rote-memory task appeared to be desirable for the study of such changes, but the lists of words or syllables or digits which are customarily used for this purpose in psychological experiments were ruled out because it seemed likely that older subjects would regard them as pointless and not worth serious effort. We accordingly devised a task which we hoped would be interesting—it did in fact prove to be so—and which would be in line with the other skilled tasks we had used.

The subject sat facing a box containing a row of ten small electric bulbs spaced horizontally at 2-inch intervals. Below and in front of each bulb was a morse-key. The lights and keys were numbered 1–10

* The account of this experiment is based on work reported in Nuffield Research Unit into Problems of Ageing *Report No. 9*, by H. Kay, dated March 1950.

from left to right by means of figures about an inch high placed between the bulbs and the keys.

The bulbs and keys were connected to an apparatus arranged in such a manner that, when one bulb was lit, the pressing of one of the morse-keys would put it out and light another bulb. This could in turn be put out and a third bulb lit by pressing another of the morse-keys, and so on for a series of any length up to ten. At each position in the series only one of the keys was 'correct'—i.e. would cause the light to change—the rest having no effect. The task set the subject was thus one of learning a series of keys which would produce a series of changes in the lighting of the bulbs.

There were 10 subjects in each decade from the twenties to the sixties, i.e. 50 subjects in all. Considerable care was taken to equate the different age-ranges as regards occupation and general background—for instance each group of 10 contained 7 business and professional and 3 non-clerical subjects.

Each subject was shown the apparatus, its working was explained and demonstrated, and type-written instructions were left beside him in case he wanted to go back over any point. He was then required to discover and learn a sequence among the keys 1–5, repeating the series over and over until he had pressed the correct sequence of keys without making any errors for two consecutive 'trials'. Having achieved this, he learnt another sequence of five on keys 6–10, until the same criterion of performance was reached.

As soon as he had learnt the second series he was asked to repeat the first series. If he did not do so without error on the first 'trial', he went on to further trials until he achieved a correct performance. Having done so, he repeated the second series in a similar manner.

Results

The pressing of each key was recorded on a paper strip moving over a constant-speed drum. From this record three main scores could be obtained for both learning and relearning, namely:

(*a*) The number of trials required, up to but not including the 'criterion' trials.

(*b*) Time taken over the trials up to but not including the 'criterion' trials.

(*c*) The number of errors made—i.e. the number of times wrong keys were pressed.

These three scores were not, of course, independent. Trials were dependent upon errors to the extent that they had to continue until the last error had been eliminated. Time was partly dependent upon the number of trials, and upon the number of errors made in each trial, i.e. upon the number of keys struck, but it also varied with the 'tempo' of the performance, i.e. the time taken to strike each key. While, therefore, the score for errors is probably the most important of the three, all have some contribution to make to the general picture of performance at this task.

We will consider these scores for the *learning* and *relearning* of the two series in turn.

Scores for learning. These are set out for the five decades in Fig. 9.1. The scores for the first and second series were, with minor exceptions, closely similar and we have accordingly taken the two series together when calculating the means shown in this figure.

Three points about these scores deserve to be noted:

1. It will be seen that the subjects in their thirties made about the same number of errors as those in their twenties, and took slightly *fewer* trials, but a somewhat longer time—i.e. they took a substantially longer time per trial. The thirties were clearly working in a slower and more deliberate manner than the twenties but no less accurately.
2. The subjects in their forties required considerably more trials and made substantially more errors than those in their thirties but took very little more time. It seems clear that the forties were showing the reverse tendency to the thirties by maintaining speed at the expense of accuracy.
3. Beyond the forties all three scores rose rapidly so that the sixties required on the average more than twice as many trials, made about three and a half times as many errors, and took about four times as long as the subjects in their twenties.

Taking all the results together it seems clear that, on the average, performance showed a continuous fall with age. This appeared first as a slowing in the thirties, then as a fall of accuracy in the forties, and finally as a fall of both accuracy and speed in the fifties and sixties.

One further point about the changes of performance between the different decades is not brought out by Fig. 9.1. It is that the *variability* of performance increased very greatly with age. In Table 9.1 are shown the standard deviations of the three scores. It will be seen that

all rose consistently with age. Actually these standard deviations are roughly proportional to the corresponding means, so that the relative variability of the different decades is more or less equal. In absolute

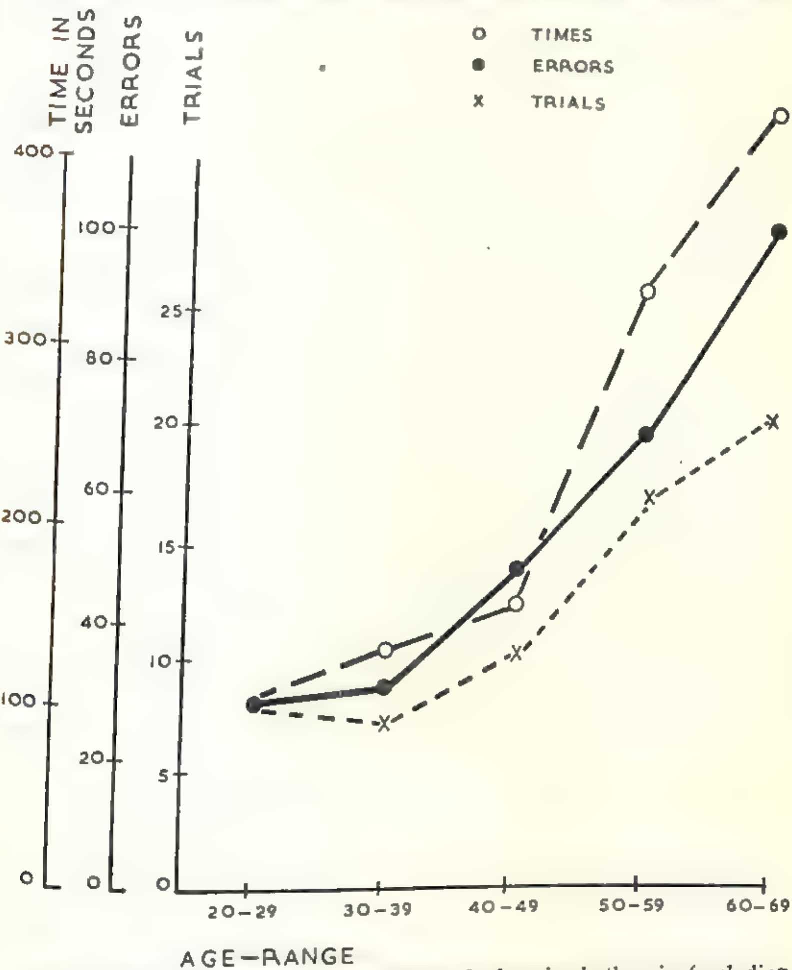

FIG. 9.1. Times, errors, and trials per subject for learning both series (excluding criterion trials)

The scales on the ordinate are arranged to make the points for all three scores by the subjects in their twenties coincide. All three scores show striking increases with age.

measures, however, the variation between subjects in the higher age-ranges is very much greater than in the lower, so that whereas some subjects were considerably poorer than the group-means would suggest, others were putting up relatively good performances.

TABLE 9.1. *Standard deviations of the learning-scores (per subject) for Series I and II together*

Age-range	*Trials*	*Errors*	*Times (in seconds)*
20–9	2·4	15	20
30–9	4·3	18	37
40–9	5·1	22	36
50–9	6·9	44	86
60–9	11·3	70	153

The variability between subjects was very much greater in the higher age-ranges than in the lower.

Scores for relearning. The average numbers of trials required, errors made, and times taken for relearning the two series are set out in Fig. 9.2, from which it will be seen that all these scores increased markedly with age. Correspondingly the numbers of subjects, set out in Table 9.2, who recalled both series correctly at the first trial fell sharply with age, until in the fifties and sixties no subject recalled both series without error.

TABLE 9.2. *Numbers of subjects recalling series correctly at first relearning-trial*

Age-range	*Series I*	*Series II*	*Both series*
20–9	10	8	8
30–9	4	8	3
40–9	4	5	3
50–9	1	3	0
60–9	1	1	0

The number of subjects who recalled correctly at the first relearning trial decreased strikingly with age.

It is noteworthy that the increase of error with age appeared earlier in the relearning than it did in the learning-task, being pronounced among the subjects in their thirties, who had been in learning as accurate as the twenties.

The relearning scores generally support the scores for learning. As the age of our subjects increased not only did learning-performance fall but there was also less retention of what had been learnt. The changes with age were in both cases very substantial, although it must

be borne in mind that the variability between subjects increased among the older subjects so that some were much worse and some much better than the average.

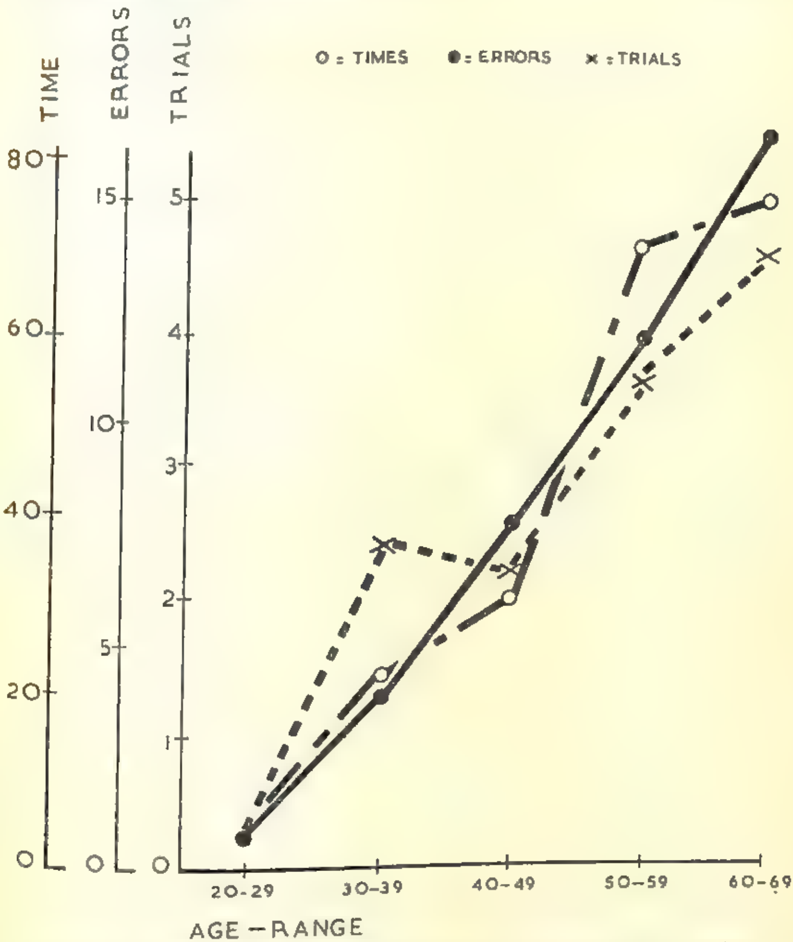

FIG. 9.2. Times, errors, and trials per subject for relearning both series (excluding criterion trials)

The scales on the ordinate are arranged to make the points for all three scores by the subjects in their twenties coincide. All three scores show striking increases with age.

Discussion of the results

Some of the changes of performance that went with age among our subjects are probably to be explained by different manners of approach to the experiment. Those in their twenties seemed to approach

the learning-task without any very clear idea of what they were going to do, and allowed the task itself to dictate their method. The subjects in the thirties and forties were more circumspect, carefully examining the lights and the keys before beginning their first trial. They asked questions about the method of learning they should adopt, often of a deductive nature: 'Then I don't need to look at . . .', &c. As a result they usually started with some definite idea in mind of how to proceed. It was probably because of this that their performance at the learning-task was so much better than it was at the relearning. The learning-task was—very much more than the relearning—a matter of *problem-solving*, in which the superior application and technique of the subjects in their thirties could show to advantage.

The approach of the subjects in their fifties and sixties was, like their achievement, much more varied. Some showed the same characteristics as subjects in their thirties and forties, and when examining the apparatus were clearly trying to evolve a technique. Others, however, seemed to have difficulty in understanding the task. Often their questions revealed that they had erroneous preconceptions about the nature and purpose of the apparatus, and that their lack of comprehension was due to their having difficulty in modifying these preconceptions in the light of the instructions.

A more detailed understanding of what was happening during learning, as opposed to the way in which the subjects approached the task, can be gained from a study of the *errors*. The simple averages shown in Fig. 9.1 might, if they were unsupported by any other evidence, lead us to suppose that, when a subject failed to strike a correct key 'first shot' in any particular trial, his knowledge at this point was a 'blank' so that he was reduced to trying keys more or less at random. The greater number of errors made by the older subjects would on this view have been due to their taking longer to fill in these 'blanks'. Examination of the errors on the various keys made it quite clear, however, that, especially as regards the first error at any position in any trial, the subjects certainly were *not* hitting at random, but were tending to concentrate their errors on particular keys.

The 'first errors' made at each position in the two series are set out systematically in Table 9.3. Two points about the distributions in this table seem clear:

(*a*) As was to be expected, errors were very rarely due to striking the key which was 'correct' for the last serial position, i.e. the key struck previously. On keys which had come further back

than this in the series there were, however, appreciable numbers of errors, the number rising as the distance back increased.

(*b*) At every serial position except the first of Series I, the highest proportion of errors was due to the substitution of the key next in the series for the one which was 'correct' at that position. Some of these 'anticipatory errors', as they have been called in previous studies of serial learning, were also on keys further ahead in the series, the number tending to fall off as the distance ahead increased.

TABLE 9.3. *Distribution of first errors*

Correct key	*Error-keys*				
SERIES I	*2*	*4*	*3*	*1*	*5*
2	..	11	31	63	20
4	3	..	78	24	16
3	34	8	..	84	62
1	49	43	0	..	145
5	71	23	22	4	..
SERIES II	*7*	*6*	*10*	*8*	*9*
7	..	24	7	21	8
6	1	..	62	29	52
10	27	4	..	71	52
8	49	38	0	..	70
9	39	35	32	5	..

The entries in the column under each 'error-key' are the numbers of times that key was struck instead of the correct key given on the left of the table. The error-key columns are arranged in the order in which the keys came in the series in order to illustrate the points noted in paras. (*a*) and (*b*) above. Thus, when searching for Key *3* (Series I), Key *4* which had just been correct was struck eight times; the last correct key but one, i.e. *2*, was struck thirty-four times; the next key in the series, i.e. *1*, was struck eighty-four times; and the next key but one, i.e. *5*, was struck sixty-two times.

It would appear from Table 9.3 that at each point where they made mistakes the subjects had a clear knowledge of the key they had just struck, but had difficulty in distinguishing the key which was correct at that point from others further ahead or further behind in the series, especially the one immediately ahead. Whereas, however, this is a reasonable inference from the *group* results, and was probably true in many individual cases, examination of the *individual* results indicated that it was by no means wholly true. Often a subject would go on hitting not just *a* wrong key but the *same* wrong key trial after trial.

When it is borne in mind that the correct key had eventually to be hit in every trial, it seemed impossible to believe that the subjects were merely muddled or uncertain. Rather they seemed to have a *definite predilection* for particular wrong keys at some points.

The complexity of the events which occur during the course of learning make it a wellnigh impossible task of statistical calculation to prove this point in a general way, but one outstanding case seemed clear enough. Let us consider the next-to-last key of the first series—i.e. Key *1*. It will be seen from Table 9.3 that Key *5*, the last in the series, was very frequently hit instead. If the subjects had merely been confused at this point and unable to discriminate between Keys *1* and *5*, we should expect that Key *1* would have had at least an even chance with Key *5* of being hit. The individual results showed that this was not so, but that the subjects in their fifties and sixties hit Key *5* more often than Key *1* to an extent likely to have occurred less than 1 in 100 times if the chances had been even.

It should be noted that this repetition of errors meant that errors made during the early trials were tending to persist. It seemed that during the early trials the subjects built up a pattern of responses, and that they tended to impose this pattern on the task in later trials in spite of evidence that it was wrong. Learning during the later trials thus tended to be not a filling in of 'blanks', but a *modification* of this initial pattern. It is worth noting, in support of this point, that often when an error was about to be eliminated the subject would move his hand towards the error-key but at the last moment avoid pressing it, making some remark such as 'No, *not* that one'.

It seemed that these patterns not only were built up during the early trials, but were to some extent the result of expectations and procedures brought to the task. For instance, although it was explained to subjects that the order of keys was random, it seemed that many had expectations about the order, such as that one key in the series would not be at the same end of the row as the last: as one subject put it, 'I was working on the principle that if I hit a correct key at one end, I then tried the other.' Other subjects tended, when unable to locate the correct key, to adopt some systematic procedure such as going along the row from left to right and back again.

One fairly general tendency which appeared to have been brought to the task concerned the second key in Series II, i.e. Key *6*. It will be seen from Table 9.3 that the subjects hit Key *9* at this point more often than would have been expected on the 'anticipatory-error' principle

that the frequency of errors tends to be less on keys a long way on in the series. This appeared to have been largely due to a carry-over from Series I. Going from left to right, the first correct key in both Series was the second in the row, i.e. Key *2* in Series I and Key *7* in Series II. The second correct key in Series I had been the fourth in the row and the subjects seemed to have expected that this key (Key *9*) would be the second correct key in Series II also, although they had been told that this series was different from the one previous. In their first trial 22 out of the 50 subjects hit this key before trying others—twice as many as hit Key *8*, which was the next most frequently chosen.

We do not wish to suggest that the causes we have indicated are a complete explanation of the errors made by our subjects. But, in so far as they did operate, they lead to the rather curious conclusion—for which, however, there are pointers from previous work (e.g. Oldfield and Zangwill 1938)—that learning was not entirely a matter of building up an organization of correct 'responses'. To a considerable extent it appears to have consisted in the *modification* of an organization brought to the situation or built up in the very early trials—in other words, there was in the learning a great deal of unlearning. To the extent that this was true, the difference between our older and younger subjects appeared to be not so much in the ease with which they could build up an organization of the series, as in the ease with which they could modify an organization in the light of experience after it had been formed.

Although the marked changes with age among our subjects amply fulfilled the prediction with which we entered this experiment, the findings seem rather to extend the scope of our hypothesis than to confirm the findings of earlier experiments. In almost all the other experiments it has either been clear, or there has been good reason to believe, that the main locus of change with age has been in the central mechanisms of the receptor side. This experiment stands apart from the rest in that the main locus of change appears to lie in the central mechanisms of the *effector* side. The task was essentially one in which the receptor organization needed was relatively simple, and the main requirement was to build up a *sequence of actions*. It is true that these actions were associated with changes in the display, but it was clear that these changes were regarded by the subjects much more as something which followed a correct action, than as something which preceded the next action. The changes in the display did not

act as positive signals *directing* the action at each stage in the series, but merely gave confirmation of the rightness of an action already taken. The larger number of errors made by our older subjects in building up the necessary series of actions suggests that the difficulty of organizing, which we have seen on the receptor side in other experiments, can also occur on the effector side if the conditions are sufficiently constrained.

GENERAL DISCUSSION OF THE EXPERIMENTAL RESULTS IN CHAPTERS V AND VI

Although the experiments we have outlined have been on too small a scale for firm conclusions to be drawn from any one of them, certain trends associated with age have appeared with sufficient consistency to merit a fair degree of confidence. In particular, every one of the experiments has shown changes associated with age which did not appear to be due to deterioration of peripheral mechanisms—sense-organs or muscles. These changes were rather to be located within the central mechanisms of the brain concerned with the organization of incoming data and outgoing action. They manifested themselves in different ways in the different tasks; for instance, in some they appeared as slowness, in others as decreased accuracy. Further work is needed to determine the exact conditions under which the different types of effect occur; but, in all the cases we have discussed, the cause seems to have been the same, namely the requirement to achieve some *fresh organization* of incoming data or outgoing action. Thus:

(i) In the grid-matching experiment, the striking increase in time taken by older subjects was associated with making the initial response to a display which had changed from a previous state.

(ii) In the throwing-at-a-target experiment, older subjects took relatively longer and showed relatively less accuracy than younger when the display and the motor task stood in an unusual relationship, but showed no such impairment of ability when the relationship of the display to the same motor activity was straightforward.

(iii) In the problem-solving experiments, where the chief requirement was the interpreting of data by other than pre-formed methods, there were clear signs of increased difficulty among the older subjects.

(iv) Fall of performance with age was particularly marked in the rote-learning experiment, which required the subjects to build serial organizations which were completely *ad hoc*.

(v) Even in the figure-tracing and tracking experiments the same principle seemed to be operating although the changes of organization in these were relatively simple, being occasioned by small changes of hand-movement or simple changes in the direction of swing of a pointer.

Once such an organization had been thoroughly achieved, it seemed to continue to be used without much difficulty. Thus:

(*a*) In the grid-matching experiment, whereas the older subjects were markedly slower for 'time to first attempt' throughout the experiment, their time spent making large errors showed a very substantial improvement after the first few minutes. The important difference between the portions of the task measured by these two times would seem to be that, whereas the 'time to first attempt' incorporated the time required to deal with a feature of the display which had changed, the large errors were due to a feature of the display—misalignment of the grids—which remained constant throughout the experiment, and could, therefore, be comprehended once for all at the beginning.

(*b*) In the inspection experiment, in which a standard of judgement could be built up at the beginning of the experiment and thereafter 'held in mind', the older subjects—at least those up to the early sixties—showed a performance which, although initially poorer, very rapidly improved to approximate equality with that of younger subjects.

We may note in this connexion that it has several times been demonstrated that, although scores on intelligence-tests fall off rapidly in later middle age, scores on vocabulary-tests fall off very little (e.g. Foulds and Raven 1948, Raven 1948). Whereas intelligence-tests essentially involve the comprehension and organization of fresh data, the main requirement of vocabulary-tests is the direct use of knowledge (i.e. pre-formed organizations) already in the subject's possession. Indeed, it appeared that sometimes it is difficulty of modifying a pre-existing organization which causes impairment of performance among older people. In the learning experiment, for instance, it was clear that in many cases the main difficulty lay not so much in learning

the sequence required, as in unlearning a sequence which contained a number of errors. Again, in face of the very difficult data presented in the logical-thinking experiment, older subjects showed a much greater tendency than younger to produce answers in terms of past experience and pre-formed opinions, instead of organizing the data itself in the manner required by the instructions.

In all the experiments we have done except the figure-tracing, tracking, and learning experiments, the locus of the changes associated with age appeared to be more in the power to organize and comprehend incoming data than to shape and organize the action taken. In other words, these changes were more on the receptor than on the effector side. Even in the figure-tracing and tracking experiments there appeared to be a strong probability that receptor functions were to some extent responsible for the changes of performance observed to go with age, although these changes were essentially in effector performance. The highly important role of receptor mechanisms in our experiments may, of course, have been due to an accident of selection when we chose our experimental tasks. But it also raises the important possibility that, in normal skilled activity, effector mechanisms do in fact set limits less often than is commonly supposed. The reason why this appears likely can be seen when we consider the conditions under which the compensatory tendencies we observed among our older subjects are able to operate.

It seems clear that achievement at any task cannot be satisfactorily regarded as proportional to the sum of the relevant capacities plus motivational factors that are brought to bear upon it, but that a subject attaches to any task a standard of achievement which he will attempt to maintain despite changes of conditions under which the task is performed or deficiencies in his own capabilities. Any impairment of his capabilities will not, in general, lead to a commensurate fall in achievement, but whenever possible will result in a change of method of carrying out the task which will enable achievement to remain constant, although perhaps at the expense of increased effort. For easy tasks these compensatory tendencies will result in there being little change of achievement, even when impairment of capability is quite severe. Indeed some over-compensation may occur which leads to the task being performed *better* than it would have been had there been no impairment of ability. In the case of harder tasks, some fall in achievement is likely to occur because the discrepancy between the demands of the task and the subject's capacities is too great for any

compensatory tendencies to be adequate. A close analysis of performance in these cases seems likely to reveal, however, that it is often only one part or aspect of a total complex task which is causing difficulties of this kind, and appropriate measures of performance will show a marked deterioration in the part or aspect concerned but not in others.

It is obvious that compensatory changes in performance can occur only to the extent that the task or portion of the task concerned permits of attack by a variety of slightly different methods, allows variations in the timing of constituent reactions, and so on. It is also clear that the extent to which these conditions occur is largely dependent upon the extent to which the method and timing of the task are under the subject's own control. Where such control can be fully exercised, compensation is likely to occur, but where the performance is narrowly constrained in either the form or timing of the constituent reactions, compensation will be virtually impossible. It can be readily seen that receptor functions, in so far as they deal with events of external causation impinging upon the subject, are essentially less under his control than effector processes initiated by his own central mechanisms, and therefore permit less compensation for deficiencies of ability, and are likely to break down sooner. Where rigid constraints are placed upon effector processes, as they were in our learning experiment by the requirement to learn a definite serial order of actions, effector functions are likely to break down just as rapidly as receptor.

VII

PRELIMINARY STUDIES IN INDUSTRY

It had from the beginning been our aim to extend our work from the laboratory into industry, not only with a view to gaining a more direct understanding of the changes accompanying age as they affect industrial skill, but also in order to check our experimental findings against data from performances which are long-continued instead of lasting only for half an hour or so. This latter point is important because it is probable that many subjects can keep up a level of performance for a short time that they would be unable to maintain over a long period. It is our hope eventually to attempt controlled experimental studies within industry, but practical considerations dictated that for the preliminary stages we should obtain our data from existing records.

The transition from the laboratory to industry was fraught with a number of severe methodological problems mainly deriving from three sources:

(*a*) For a study of skilled performance it was clearly necessary to concentrate our attention or operations which could be broadly classed as production-work. This meant, however, studying groups of older people who were highly selected, as the proportion of older people on production-work appears to be substantially lower than the proportion of younger. Doubtless this is due to some men gaining promotion in middle age, and to others being moved on to other work because they are unable to maintain adequate efficiency. But whether selection has been upward or downward, older people who remain cannot fairly be compared for efficiency with younger men on the same operations.

(*b*) In addition, any comparison of younger and older in terms of attainments, such as might be made on the basis of piece-rate earnings, requires the study of large groups of people with a wide age-range all doing *exactly* the same work. In our experience this is seldom, if ever, possible, because—even if a large group of people is found doing what is nominally the same work—minor differences between the machinery used or the articles being made may imply profound differences in the

psychological tasks which are being set to different members of the group, and make comparisons at best extremely hazardous.

(*c*) Many of the operations on which there is a high proportion of older people, and which are therefore of special interest from our point of view, are of an unstandardized nature, e.g. highly-skilled tradesmen's and craft operations, so that, even if all other conditions could be satisfied, it would be almost impossible to assess performance by quantitative measures.

These difficulties seemed to us to preclude the use of production-statistics as a general method for comparing older and younger, and to indicate the necessity of devising some way of using data from many small working-groups rather than from a few large ones. We accordingly decided to give our main attention to the *incidence of older people on different operations,* and to deal not with absolute measures for any operation or class of operations but with *comparisons between them.* This method had the advantage that we could pool data from the many small groups with which it seemed necessary to deal, and appeared to minimize the chances of false inferences due to selection in the higher age-ranges. We recognized that the age-distributions on individual operations and in particular factories were liable to distortion by a number of extraneous factors such as recruitment and retirement policies, and the age-range of labour available in the district both in the present and the past. The relating of the types of skill demanded by various classes of work to the age-distributions on a large sample of operations in several different factories seemed, however, the best method we had available for obtaining quickly an outline view of what types of work older people were and were not doing, on the basis of which detailed studies could be built at a later date.

Twenty-four factories were visited and satisfactory data were obtained for ninety-five operations. The factories belonged to firms engaged in the production or processing of:

automobiles (two firms); ballbearings; explosives; furniture; lace (six small firms, treated together as a single unit—they were all in one area and all included the same operations); leatherhides; machines, machine-tools, and other specialized plant (three engineering firms); paint; photographic apparatus; precious metals; radio and television sets; radio valves and lamps; telegraph equipment; textiles (two firms); tires.

In the main, firms were selected for study which were known to possess good records, and operations were chosen which were likely to be of psychological interest, or on which the proportion of older

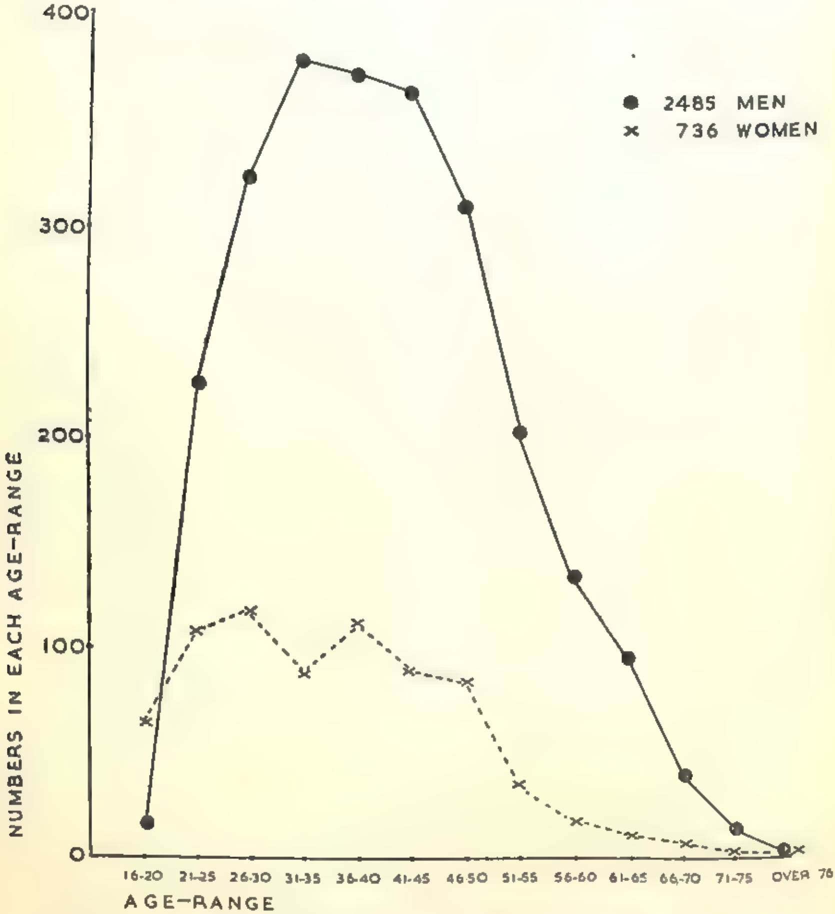

FIG. VII. 1. Age-distribution of the whole sample

There was a striking fall in numbers of both men and women from the fifties onwards.

people was unusually high or low. We had, of course, no guarantee that the sample thus obtained would be representative, but we considered that this was not of crucial importance for our particular purpose. From what little information we have been able to obtain, the proportions in the various age-ranges were fairly similar to the proportions of the corresponding age-ranges in the general population

employed on production-work, but we cannot claim to be confident on this point.

The working-groups on the operations studied were of very varying size. We felt it justifiable, however, to include small groups and even a few single workers, because it was often these who gave the clearest insight into what appear to be the changes of performance associated with later middle and old age.

The numbers falling into each half-decade are shown in Fig. VII.1, from which it will be seen that there was a very striking fall in the proportion of workpeople in our sample from the fifties onwards. Why this should have been so in spite of the fact that we were making special efforts to obtain a full quota of older people is not easy to say, but in our present investigation we were not concerned to do so. Our purpose was to study variations *within* this overall distribution. We are undertaking a study of the more general problem which we hope to report in due course.

TREATMENT OF THE DATA

When measuring the incidence of older workpeople on the various operations, we tried to keep in mind the requirements of two different interests:

(i) a factual statement of what work older people are actually doing, and

(ii) an assessment of the kind of work typically done by older people.

The first of these requires that we should plot *age-distributions*, and when comparing one class of operations with another we have to sum the individuals in each class. For the second, we need to take *operations* as our units. We did this by assigning to each operation a unitary age-index derived fom its age-distribution, and it was in terms of these indices that we made comparisons between one class of operation and another. From the statistical point of view, it is obvious that the first type of treatment gives each operation weight in the final results in proportion to the number of individuals it contains, so that large operations have more influence than small. The second type of treatment gives equal weight to all operations whatever their size, so that individuals on operations where the numbers are small have more influence upon the final results than individuals on operations where the numbers are large.

Some difficulty was experienced in selecting a measure which could be taken as a unitary index of the age of the people employed on an operation, but after many careful examinations of the age-distributions we chose the *mean age of the upper half* of the group. This appeared to represent the incidence of older people better than the mean or a percentile of the whole group, or the proportion of people over some arbitrarily chosen age. It retains most of the advantages of a straightforward mean, and at the same time pays most attention to the upper part of the age-distribution, where our principal interest lay. It is, of course, crude in many ways, and we might have devised a better measure had we been able to work with more elaborate data.

The examination of the age-distribution for each operation, and the calculation of the mean age of the upper half, was the first stage in treating our data. We then proceeded to classify the operations according to a number of variables of interest, either because of their bearing on hypotheses derived from the laboratory experiments or because there were indications from our own observations that they might be associated with age. Finally, the findings of this procedure were checked by a further examination of the *pooled* age-distributions of the various classes of operation which appeared to be of interest.

In following this procedure we had difficulty in deciding how far the results for men and women should be kept separate. The age-distributions in Fig. VII.1 show clearly that there was a greater proportion of women in the younger age-ranges—or, perhaps more accurately, a smaller proportion in the older ranges. The reasons are unlikely to be in dispute—the call-up of men in the 'teens and the marriage of women in the twenties—but it is not these which constitute the main problem. The question is whether, when an operation performed by women falls low in the age-scale, it is because women are employed on it, or because it is a job suited better to younger than to older people. If the first view is correct, men and women should be kept separate when treating results. If the second is correct, they should be combined. We shall give below one piece of evidence in favour of this second view; but almost certainly both are partly right, and we have, therefore, considered it best to keep men and women separate when treating the results.

FINDINGS

For the purpose of analysing the data we classified the operations in four different ways: first, into broad types denoting kinds of work

commonly distinguished in industry; second, according to size of the working-group; third, according to system of payment, i.e. individual piece-rates, group piece-rates, and time-rates; and fourth, according to whether or not the operation was under some kind of pressure for speed—or, as we have termed it, *time-stress*. We shall deal with each of these classifications in turn, but as the first yielded negative results and the second yielded results of doubtful significance, we shall take these after the other two.

A. *System of payment*

It is often held that because people get slower with age, time-rates are favourable to older people and individual piece-rates are unfavourable. Group piece-rates tend to be a matter of dispute: some regard them as favourable because they do not impose the same speed-pressure as individual piece-rates; others maintain that, although the incentive of individual piece-rate earnings is absent, the group exerts a social pressure to keep up the pace which may be highly unfavourable to older members. By analogy with the findings of our experiments, it would be reasonable to suggest that time-rates have the additional advantage for older people that they give opportunity for greater accuracy, such as our older experimental subjects

TABLE VII.1. *Operations divided according to system of payment*

	Age-range in which 'mean age of upper half' of the workpeople fell				
	Twenties	*Thirties*	*Forties*	*Fifties*	*Sixties*
Men					
Individual piece-rates	..	4	12	3	4
Group piece-rates	..	..	16	2	2
Time-rates	..	..	3	4	1
Women					
Individual piece-rates	1	11	11	3	1
Group piece-rates	1	2	..	..	..
Time-rates	..	1	6	3	4
Men and women together					
Individual piece-rates	1	15	23	6	5
Group piece-rates	1	2	16	2	2
Time-rates	..	1	9	7	5

There was a tendency for operations paid at time-rates to come higher in the age-scale than those paid at individual or group piece-rates.

displayed, to show to advantage. We had evidence that in many cases it was to secure greater accuracy that time-rates were paid.

The operations studied were therefore divided according to system of payment as shown in Table VII.1. It will be seen that there was a

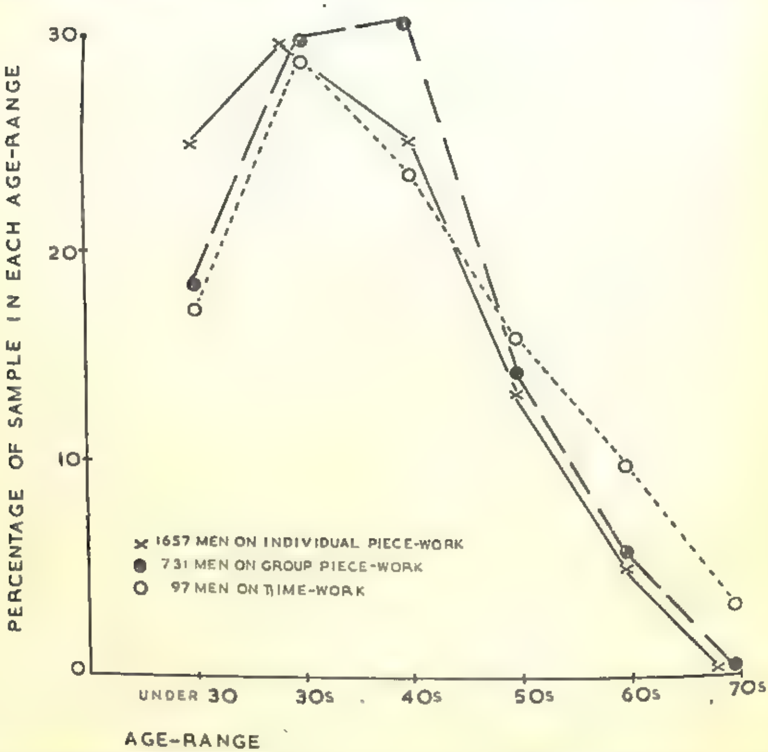

FIG. VII.2*a*. Age-distributions of men paid by individual piece-rates, group piece-rates, and time-rates

Operations paid at time-rates tended to have a higher proportion of older work-people than those paid at piece-rates.

tendency for operations paid at piece-rates, both individual and group, to have a substantially lower 'mean age of upper half' than those paid at time-rates, but that all three systems of payment ranged widely over the age-scale. It should be noted that group piece-rates, although intermediate between the other two, came closer to individual piece-rates than to time-rates.

The age-distributions graphed in Fig. VII.2 show a similar tendency for the proportion of older people to be higher on operations

paid at time-rates, although the absolute numbers of people in our sample who were paid at time-rates were small. It seems, therefore, if our sample can be regarded as typical, that although the incidence of

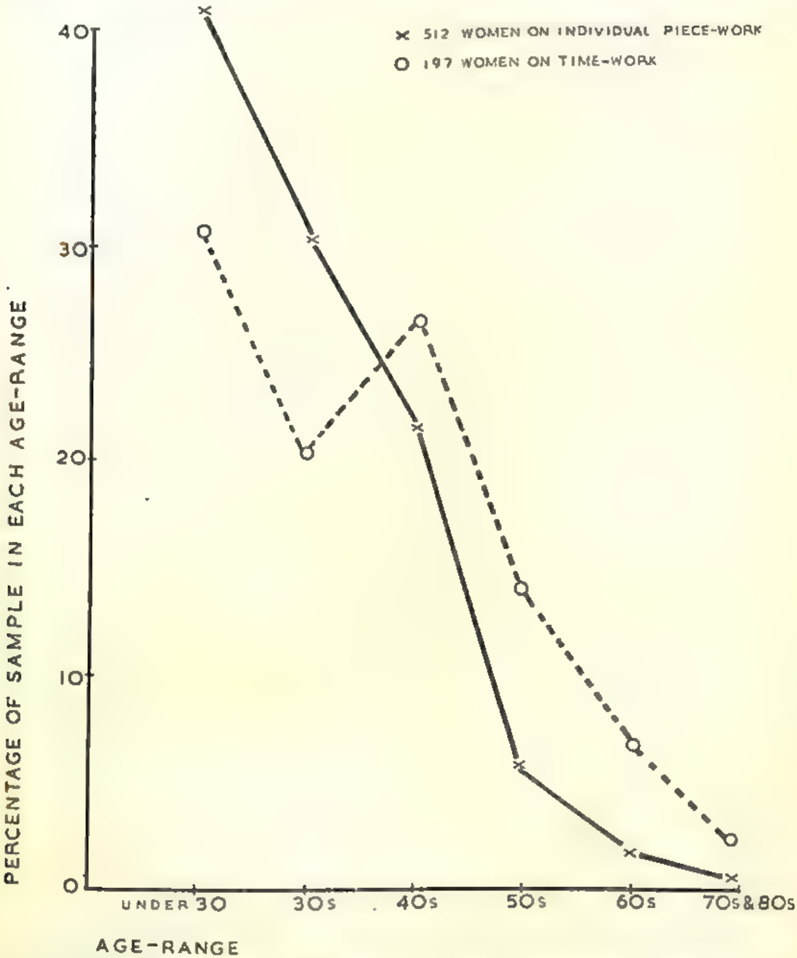

FIG. VII.2*b*. Age-distributions of women paid by individual piece-rates and time-rates

Operations paid at time-rates tended to have a higher proportion of older work-people than those paid at piece-rates.

older people tends to be higher on operations paid at time-rates than on those paid at piece-rates, a very substantial number of older people are engaged on piece-work.

B. *Timing characteristics*

It would seem important to recognize that system of payment *as such* is not likely to affect the incidence of older people on an operation. It is rather that system of payment goes with certain characteristics of the demands made by the operation, and that unfavourable characteristics are associated with individual piece-rates and favourable ones with time-rates. It seemed probable to us that the most important difference between piece- and time-rates was that the former usually applied to jobs where speed was of paramount importance and the latter were paid when some such quality as accuracy was more important than speed.

TABLE VII.2. *Relationship between age and length of time-cycle at machine-feeding operations*

	Mean age of upper half of workpeople	*Approximate time required for one cycle of the operation (in seconds)*
Men . .	33	10–15
	34	24
	41	1
	41	6–8
	45	10–30
	46	4
	47	3–5
	57	40
	58	3
	62	2–3
	64	90
Women . .	33	2
	33	8
	33	4
	34	3–4
	40	15
	41	2
	61	2

There was no tendency for the operations having longer time-cycles to come higher in the age-scale.

It seemed clear that the speed which was unfavourable to older people was not a matter of the length of time required to complete each cycle of an operation. In Table VII.2 are given the 'mean ages of the upper halves' and the lengths of the time-cycles for the operations making up the class 'machine-feeding' (see page 138). It will be seen that there is no correlation between the two measures.*

* The rank correlation coefficients between age and length of time-cycle are very small (see Statistical Appendix).

Inspection of the results suggested that a more promising definition of the speed unfavourable to older people was to be found in terms of the amount of *time-stress* imposed. The operations were, therefore, divided again into two categories, thus:

1. *Operations in which some time-stress was present*

Under this heading were included two major classes of operation:

(*a*) Fifteen operations where the work was *rigidly paced*, in the sense that operatives were compelled to keep up with a machine or conveyor-line and to complete each cycle of the operation within a rigidly fixed time (cf. the tracking experiment). This class essentially consists of operations where failure to maintain pace led to serious errors of omission, and where there was no opportunity for pauses in the work.

(*b*) Thirty-four operations where, although the pace was more flexible, there was *speed-pressure* in the sense that the nature of the operation or the working-group placed a greater stress upon speed than upon accuracy (cf. the figure-tracing experiment). Essentially this class includes all operations paid at individual or group piece-rates, except those in (*a*) and those where there was some mitigating circumstance listed below.

2. *Operations in which speed was secondary to accuracy or where time-stress was in some way mitigated*

Under this head were included twenty-two operations paid at time-rates—i.e. operations where the speed and pace of work were essentially under the operatives' own control—and a further twenty-four which, although paid at individual or group piece-rates, possessed one or both of the following characteristics tending to reduce time-stress:

(*a*) The machinery or the working-group set a pace which was such as to permit or enforce frequent pauses in the work.

(*b*) The operation was such that it had to be carried out deliberately and with more stress upon accuracy than upon speed, e.g. certain highly-skilled tradesmen's or craft operations.

The results, shown in Table VII.3, of dividing the operations according to this multiple criterion are very striking. The 'mean ages of the upper halves' for operations involving time-stress fall with two exceptions in the forties or below, and those for operations where time-stress is absent fall with one exception in the forties or above.

TABLE VII.3. *Operations divided according to whether or not they involved time-stress*

	Age-range in which 'mean age of upper half' of workpeople fell									
	21–5	*26–30*	*31–5*	*36–40*	*41–5*	*46–50*	*51–5*	*56–60*	*61–5*	*66–70*
Men										
With time-stress	..	..	2	2	10	8	..	..	..	..
Without time-stress	..	..	..	..	6	7	4	5	6	1
Women										
With time-stress	1	1	8	5	7	3	1	1	..	..
Without time-stress	..	..	..	1	2	5	2	2	2	3
Men and Women together										
With time-stress	1	1	10	7	17	11	1	1	..	..
Without time-stress	..	..	..	1	8	12	6	7	8	4

There was a striking tendency for operations involving time-stress to come lower in the age-scale than those which did not involve time-stress.

The actual age-distributions, shown in Fig. VII.3, amply confirm the findings of Table VII.3. It will be seen that, although the distributions for work in which time-stress was present and in which it was absent overlap, the proportion of older people on the latter was very substantially higher than on the former. Indeed, after the age of 55 hardly any of the people observed were doing work involving time-stress. It should be noted that this separation was found in each of the types of work discussed on pp. 138–43 and in each of the factories visited in which substantial numbers enabled a reliable comparison to be made. It also appeared in a number of comparisons between operations which could be regarded as fairly strictly comparable in other respects.

One incidental point about the distributions in Fig. VII.3 deserves to be noted. It is that the proportions of men and women in the various age-ranges on work not involving time-stress were, except in the late forties, fairly similar. In other words, the large numbers of young women in our sample were mostly doing work involving time-stress—i.e. work which appears especially suitable for people of their age.

Our studies are not far enough advanced for us to be able to locate with certainty the difficulty that time-stress produces for older people. The fact that they tend not to be found on tasks where speed is

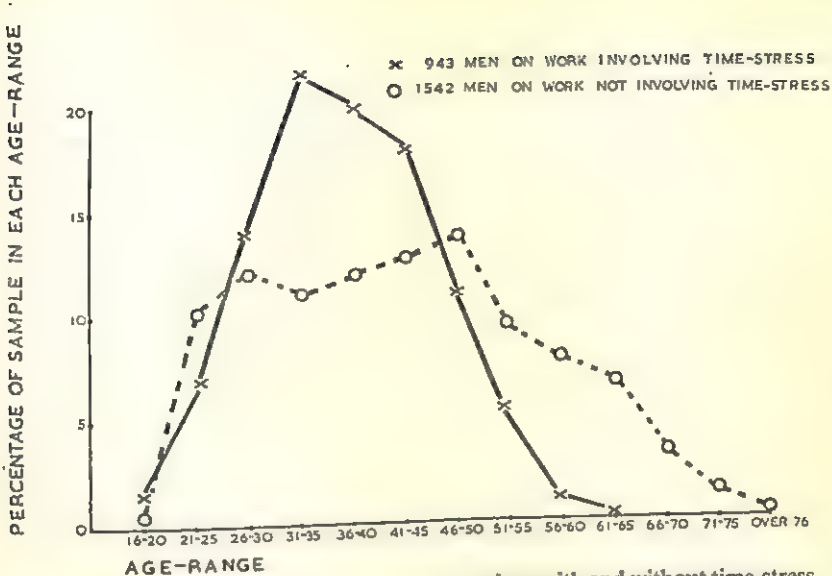

FIG. VII.3*a*. Age-distributions of men on operations with and without time-stress
Operations without time-stress tended to have a substantially higher proportion of older workpeople than those with time-stress.

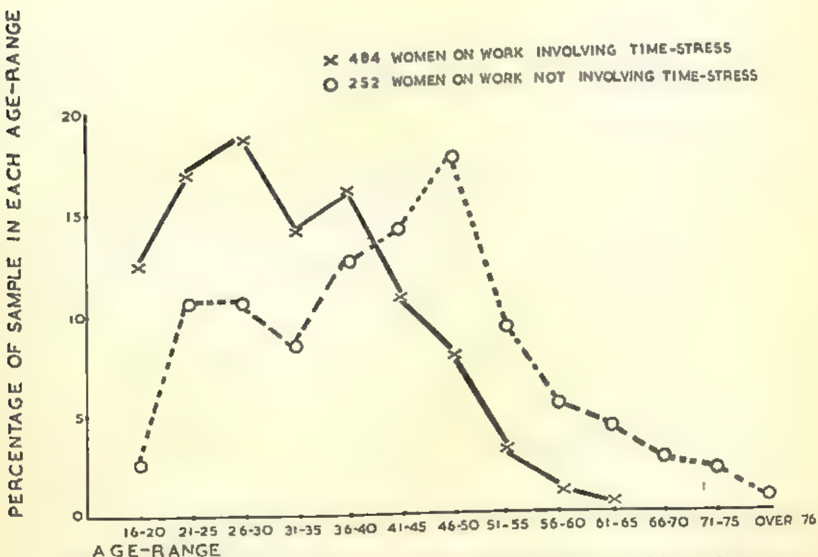

FIG. VII.3*b*. Age-distributions of women on operations with and without time-stress
Operations without time-stress tended to have a substantially higher proportion of older workpeople than those with time-stress.
The age-distribution of women on operations without time-stress was, except in the late forties, comparable with that of men on similar operations.

stressed is, of course, in line with several of the laboratory experiments in which speed decreased among the older subjects. We cannot, however, on the present evidence say for certain that the age-distributions found in industry are due to the same changes that appear to be associated with age in the laboratory experiments. It seems, for instance, possible that in many industrial operations effector mechanisms may play a larger part, in determining the changes that come about with age, than they appeared to have done in the experiments. We hope that further studies now in hand will go some way to providing an answer to this problem.

C. *Size of working-group*

We came across several opinions that older people worked better in a small group. It seemed to us that if this were true there was likely to be a higher incidence of older people on operations with small working-groups than where numbers were larger. We therefore divided those operations with ten members or less from the rest, with results set out in Tables VII.4 and VII.5. The first of these tables

TABLE VII.4. *Operations divided according to size of working-group*

Number in Group	*Age-range in which 'mean age of upper half' of workpeople fell*				
	Twenties	*Thirties*	*Forties*	*Fifties*	*Sixties*
Men					
1–10	..	..	5	2	5
Over 10	..	4	26	7	2
Women					
1–10	1	6	5	3	4
Over 10	1	8	12	3	1
Men and women together					
1–10	1	6	10	5	9
Over 10	1	12	38	10	3

There was a slight tendency for operations having 10 or less members to come higher in the age-scale than operations with larger working-groups.

shows the 'mean ages of the upper halves', and it will be seen that for both men and women there was a slight tendency for the operations with ten or less members to come higher in the age-scale than the others. Table VII.5 sets out the actual numbers of individuals over

and under 50 years of age on the two sizes of operation. It will be seen that, although the majority of older people (both men and women) in our sample were employed on operations with larger numbers, the operations with ten or less members had a substantially higher *proportion* of older people—42 per cent. of the men and 23 per cent. of the women on operations with less than ten members were over 50, as opposed to 19 per cent. of men and 9 per cent. of women on operations with more than ten members.

TABLE VII.5. *Numbers of persons over and under 50 years of age divided according to size of working-group*

Size of group	*Over 50*	*Under 50*
Men		
1–10	23	32
Over 10	467	1,961
Women		
1–10	27	89
Over 10	53	567
Men and women together		
1–10	50	121
Over 10	520	2,528

Groups with 10 or less members contained a substantially higher proportion of men and women over 50.

We do not wish to lay much stress upon this finding because the tendency may have been due to some error of sampling. For instance, the investigators may have had their attention drawn to an undue proportion of small groups of older workpeople. If, however, it is not an artifact it is probably a secondary effect of time-stress, in that the speed of work can be more easily adjusted to suit individuals in a small group than it can in a large one, where conditions tend to become rigidly standardized. This is not to say that older people will show a higher productivity in a small group than in a large, but rather that they will work more happily. We have, however, some slight evidence, which would seem worth while following up, that older people may in some circumstances work not only more happily but also more efficiently in a small group consisting entirely of older people. A small group with a narrow age-range and absence of 'competition' from younger people often has a 'human' atmosphere which appears to be especially favourable to older people, enabling them to work without strain.

D. *Types of work*

As previously mentioned, the first classification we made of the operations studied was according to *types of work*. We distinguished five types thus:

1. *Machine-feeding*—the feeding of automatic machines and analogous repetitive machine-work where skill lies in the *handling of materials* rather than in knowledge of the operation of the machine.
2. *Machine-operating*—operations in which the principal skill lies in the *operation* of the machine.
3. *Light assembly and other hand-operations*—light jobs designated 'assembly' in the factories concerned, and certain analogous work involving the fitting or attaching of parts by hand.
4. *Inspection work*—the testing, grading, and examination of materials and products.
5. *Heavy work*—including operations involving considerable *muscular effort* in the handling of heavy materials, &c., and those involving a degree of *activity* which made them regarded as heavy in the factories concerned.

This classification was made not only because the classes were fairly well recognized in industry, but because it seemed that they differed in the psychological demands which they made on the workpeople concerned. Heavy work made greater physiological and effector demands than the others. Machine-feeding, machine-operating, and light assembly-work made less demands of these kinds, but required higher degrees of fine dexterity. Machine-feeding was of a more repetitive nature and required a lower degree of skill in the industrial sense than machine-operating. Inspection work was, perhaps, more than any other class a matter of receptor skill—i.e. the interpretation of data from meters, gauges, &c.—and seemed likely to be able to provide a check on the findings of the inspection experiment (Experiment 8).

The mean ages of the upper halves of the workpeople on operations classed in this way are set out in Table VII.6. It will be seen that in no class did *both* men's *and* women's operations fall markedly to one end of the age-scale, and that when men's and women's operations are taken together each class ranged widely over the scale. It seems clear, therefore, that this method of classifying the operations in our sample does not discriminate well between older and younger.

TABLE VII.6. *Operations divided according to type of work*

Type of operation	*Age-range in which 'mean age of upper half' of workpeople fell*				
	Twenties	*Thirties*	*Forties*	*Fifties*	*Sixties*
Men					
Machine-feeding	..	2	5	2	2
Machine-operating	..	..	2	1	..
Light assembly	..	1	2	2	2
Inspection	..	..	2	..	1
Heavy	..	1	20	4	2
Women					
Machine-feeding	..	5	1	..	1
Machine-operating	1	2	1	1	1
Light assembly	..	3	6	2	2
Inspection	..	2	8	1	1
Heavy	1	2	1	2	..
Men and women together					
Machine-feeding	..	7	6	2	3
Machine-operating	1	2	3	2	1
Light assembly	..	4	8	4	4
Inspection	..	2	10	1	2
Heavy	1	3	21	6	2

There was no marked consistent tendency for one type of operation to fall higher in the age-scale than any other.

Inspection of the age-distributions gave essentially the same result when operations on which time-stress was present were considered apart from those on which it was absent. It seemed, therefore, that neither in the mean ages of the upper halves of the workpeople, nor in age-distributions, were there any substantial differences between these classes of operation *as such* in our present sample. Any differences there were could be adequately accounted for by the extent to which the classes varied in the proportion of time-stressed operations they contained.

This negative finding was especially interesting in the case of inspection work and heavy work. The former, as we have said, lays special emphasis on receptor skill. It was seen in the laboratory experiments that the ability to comprehend new data appeared to fall off with age, but that when the task was repetitive (so that it allowed such comprehension, once attained, to be used with comparatively little modification) performance remained high, at least through the fifties. Most of the inspection operations we studied were of this repetitive nature, and we should therefore expect to find evidence, in the age-distribution

of the workpeople on these operations, that older people continued at them until a fairly late age.

In Fig. VII.4. the age-distributions of women, who formed 79 per

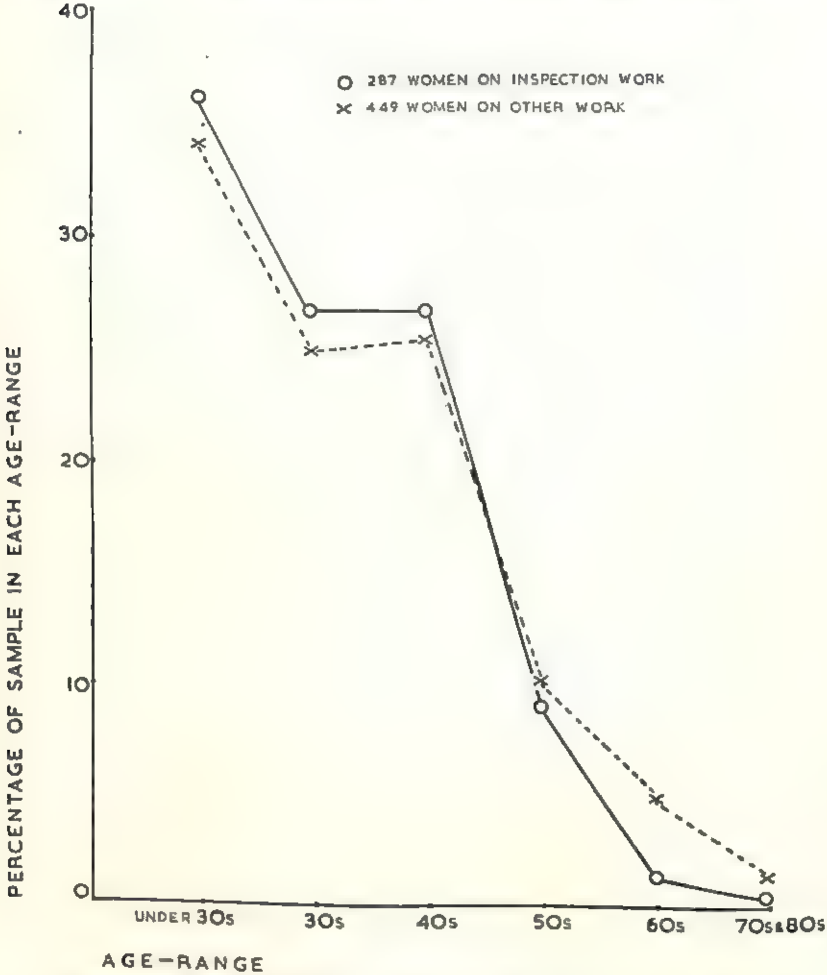

FIG. VII.4. Age-distributions of women on inspection and other work

The proportions of women on inspection and other work were very similar in all age-ranges, at least up to and including the fifties.

The method of constructing this Figure is given in the Statistical Appendix.

cent. of our sample of inspection-workers, are compared for inspection and other work. It will be seen that the two distributions are closely similar, at least until the fifties. How far this result can be taken as

confirmation of our inspection-experiment depends upon the causes of the general decline from the forties onwards in the numbers of people engaged in the kind of work we studied. The figures support

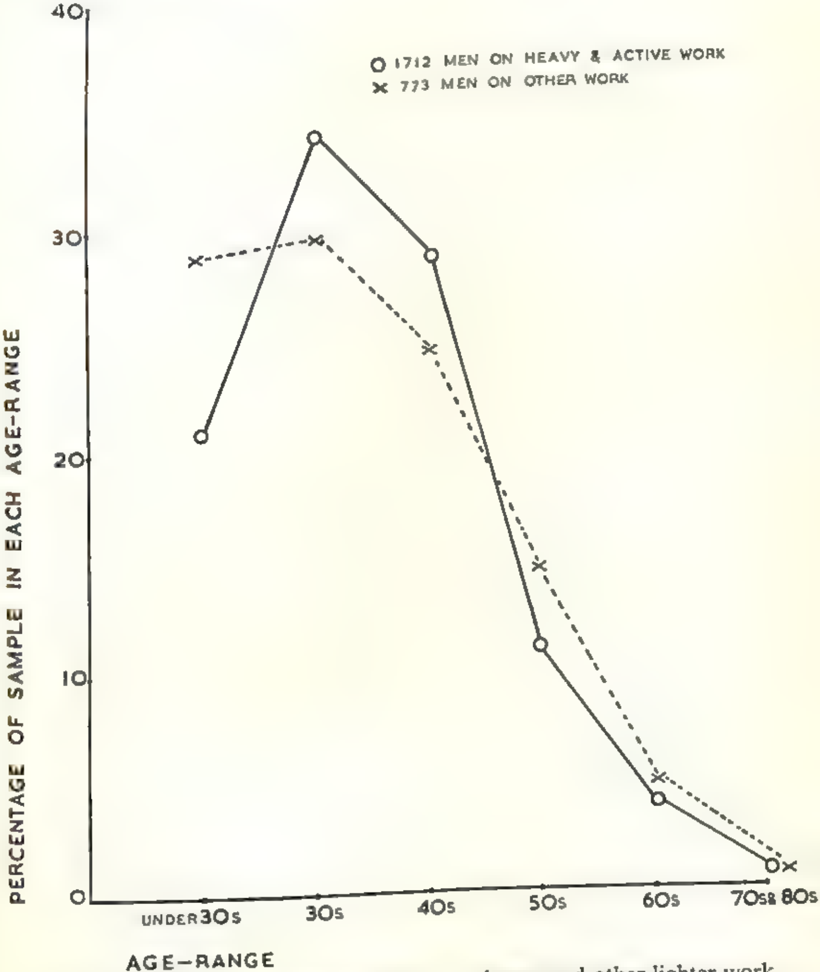

Fig. VII.5. Age-distributions of men on heavy and other lighter work
The proportions of men on heavy and other work were very similar in all higher age-ranges.
The method of constructing this Figure is given in the Statistical Appendix.

the view that, *compared with other work included in our sample,* the ability to carry on inspection-operations remains high up to and including the fifties, but it may still be that there is some decline of

ability not noticeable in our experiment but having a profound influence in industry which affects equally both inspection and other classes of production-work.

As regards heavy work, the finding that operations in this class did not fall lower in the age-scale than the lighter jobs is of interest because it runs counter to the popular opinion that heavy work is unsuitable for older people. It is also of interest because it suggests that at least some operations, which make severe physical demands upon the effector mechanism, can be carried on by a substantial proportion of older people with enough efficiency for them to be so employed. The data in Table VII.6 are fully confirmed by the curves in Fig. VII.5 which show that the age-distributions for men (who formed 93 per cent. of our sample) on heavy and lighter work were very similar. It should be noted that the same finding appeared in a number of comparisons within particular factories, between operations which differed in the degree of muscular activity required but which were closely comparable in other respects.

Time-stress was associated with a low incidence of older people on heavy work, as it was in all other classes we have examined. It is possible, however, that the reason for this is not the same in the two cases. Heavy work on which time-stress was present typically involved *continuous effort*, i.e. every item in the cycle of operations was heavy. When time-stress was absent heavy items were usually interspersed with lighter. Heavy work involving time-stress thus tended to be also *strenuous*, and it may have been this rather than speed which was discriminating against older people. Support for this view comes from the fact that a few operations which involved continuous effort without time-stress all fell low in the age-scale.

One striking finding about heavy work does not appear from Table VII.6 and Fig. VII.5. It is that of the jobs from which there was definite evidence that people moved away on account of age; fourteen, out of the total of fifteen, fell into this class. These 'moves-off' seemed more closely associated with time-stress than with continuity of effort. They are set out in Table VII.7, from which it will be seen that all the operations where rigid pacing occurred showed evidence of moves with age, and that conversely there was evidence of moves in only one of the operations where time-stress was absent.

The meaning of these 'moves-off' attributed to age is not easy to assess, because the actual incidence of older people did not seem to be different on comparable operations where they occurred and where

TABLE VII.7. *Heavy operations divided according to whether or not there was evidence of persons moving away, on account of age, before retirement*

	Operations involving time-stress		
	Operations with rigid pacing	*Operations with speed-pressure*	*Operations not involving time-stress*
Men			
Evidence of moves . .	7	3	1
No evidence of moves . .	..	2	14
Women			
Evidence of moves . .	2	1	..
No evidence of moves . .	..	1	2
Men and women together			
Evidence of moves . .	9	4	1
No evidence of moves . .	..	3	16

There was a striking tendency for there to be evidence of moves before retiring-age from rigidly-paced operations, and for there to be no evidence of moves from operations not involving time-stress.

they did not. It may be that moving away in the higher decades occurs to about the same extent but for different causes in the two cases, or it may be that several factors are operating equally in both, but that age has a greater tendency to be stated as the reason for leaving heavy operations involving time-stress than it has for leaving others. Whichever is true, it must be remembered that moves attributed to age are unlikely to be due merely to the fact that a person has lived for a given length of time, but to some change which age brings with it or which is commonly associated with age.

E. *Training*

It was not our purpose in this investigation to study problems of training for industrial work. Definite evidence of training difficulties was, however, obtained for 15* of the operations studied. It was striking that these difficulties began early—in 7 cases they began in the twenties, in 6 in the thirties, and only in the remaining 2 in the forties. It was also noteworthy that all these operations were either high-speed repetitive work involving some 'knack' or dexterity, or

* This number includes six operations not dealt with in the main discussion of results because the age-data obtained were incomplete.

work involving a display, 'set-up', or procedure which was complicated and intricate for the uninitiated. In a few cases it appeared that, when older people were allowed to learn in their own time instead of at the normal speed of the operation, they were better able to attain a satisfactory performance, although they might take some months to achieve a standard which could be reached by a younger person in a few weeks. In all these operations except one it appeared that, once the complex effector or receptor 'organization' required had been learnt, the skill could be *maintained* until a relatively late age.

In summing up the findings of these industrial studies, their preliminary character and the tentativeness of any inferences based on them must be emphasized. Within the limits of our sample, however, it was clear that older people tended to be found doing work where there was an absence of time-stress—in other words, work which could be done at their own pace, unhurried by pressure for speed, and where there was opportunity for accuracy to be displayed to advantage. There was a tendency for operations on which the numbers were small to have a relatively high proportion of older people. Among such classes of work as machine-feeding, machine-operating, light assembly, heavy work, and inspection, older people were not found on one more than another except in so far as the classes varied in the proportion of operations they contained on which time-stress was present. This fact was especially noteworthy in the case of heavy work, which makes severe demands upon the peripheral effector mechanisms, in view of the indications that the changes of performance shown by subjects in the laboratory experiments appeared to be of central receptor rather than effector origin.

We cannot at present say how far a high incidence of older people on an operation or class of operations is due to the fact that the skills involved can be *maintained* to a late age, and how far it is due to their being relatively easy for older people to *learn*. We found evidence that older people can maintain an established skill to an age considerably beyond that at which they can without undue difficulty learn a new skill. Learning-difficulties seemed typically to occur at tasks involving either time-stress combined with high degrees of dexterity or a complicated and confusing display, but may have been considerably more widespread. For instance, when a substantial proportion of older people are found on an operation it is evidence that the skill involved can be maintained, but the converse is not necessarily true. It

may be that the operation concerned was staffed with young people when it first began because older people were unable to learn the required skill to a sufficient standard or sufficiently rapidly, and that it has not been going long enough for the people who started when it was new to have reached the higher age-ranges. The problem of assessing this kind of influence upon the age-distributions of operations is complicated for the investigator by the fact that changes of numbers or of conditions during the period an operation has been in existence need to be considered as well as the date of starting. We excluded from our study operations which had been going on for only a short time, but unfortunately we were unable to obtain sufficient information about the dates at which the operations we studied began, and what changes had been made in them subsequently, for us to say just how far this kind of influence had shaped the age-distributions in our sample. Such information appears to be seldom, if ever, sufficiently complete for conclusive results to be obtained, but we have further work planned which we hope will throw some light on this obviously important point.

VIII

CONCLUDING NOTE

WHILE the scale of our investigations makes it premature to draw very much in the way of general conclusions, it would seem fair to claim that they have two contributions to make.

First, the laboratory experiments and studies in industry taken together suggest strongly that an important locus of change with age lies within the central mechanisms of the receptor side. If it is legitimate to generalize from our findings, it would appear that, as a person gets older, he finds it increasingly difficult to *comprehend* verbal or visual data, especially when these are in any way new or unfamiliar. The breakdown seems to be more in the process of *organizing* the incoming data and relating it to the *relevant* material that he brings to the situation from his past experience, than in the availability of past experience itself. Indeed the most noticeable effect of the change is that, as age increases, the subject seems to be thrown back more and more on to his past experience, so that he often finds it difficult to get away to a new comprehension of the material, even though he realizes that the situation demands that he should do so. As a result, older people seem able to deal relatively well with a situation which can be adequately met by means of what they bring to it from the past, but they find difficulty when confronting a situation which is in any important way new.

The capacity to deal with new situations does not, of course, disappear altogether. Rather it seems that the mechanisms concerned with organizing incoming data function less efficiently, requiring, for instance, a stronger 'signal' or more time than they did before. In common parlance we should say that older people maintain their achievement better when they can deal with incoming problems more or less at leisure, or where the data are full and straightforward.

The effects of this change are widespread and are probably responsible for many changes of performance which might at first sight appear to be due to breakdown of effector mechanisms. They also begin early, often being well evident by the thirties. Frequently, however, they do not lead to a substantial change of *achievement* until a much later age, because the subjects make adequate compensation for their difficulties by changes of method. Indeed, when the task is

relatively easy or there is little pressure for speed, overall performance may, at least for a time, improve with age. In particular, it appears that although speed may decrease among older people this deficiency is often more than offset by gains in quality and accuracy. Also, it seems that, even at those ages at which most subjects show some fall in performance, there is a substantial number of individuals who maintain performances comparable with those of people in their twenties or thirties.

About changes on the effector side we have less certain information. It is clear that changes of effector *performance* occur with age—for instance, slowing and changes of method—but it appears that in many cases their cause is to be located not in the effector mechanisms themselves but in the receptor mechanisms on which they depend. It seems probable, however, that when the task is such as to make severe demands upon the central effector processes, changes occur with age which are parallel to those of the receptor side.

Much of the value of exploratory studies such as ours lies, however, not in their findings but in the building up of techniques. From this point of view probably the most important contribution we have to offer is the method of analysing a total performance into components, and showing that it is often one or more of these rather than the performance as a whole that varies with age.

The simultaneous examination of a set of components makes possible the study of *method* of work in an objective form. This in turn makes possible the study of changes of method associated with age in groups whose performances show equal achievement. This procedure would seem in certain instances to reduce the severity of the problem of sampling, since equality of achievement is measurable in a way that similarity of social background, occupation, &c., is not. The problem is not, of course, entirely removed, because methods as well as achievements are likely to vary according to a subject's training and experience. When, however, it is required to compare the performances of younger and older people in industry, this method seems likely to be of very great importance, because it appears to offer a way of overcoming some of the difficulties resulting from the fact that older men and women in industry are highly selected.

The method we have used of analysing a complex performance has obvious applications beyond the study of ageing, and appears to be a valuable means of investigating many problems concerned with skills. We ourselves have already used it for investigating one other problem,

namely, flying-fatigue (Welford, Brown, and Gabb 1950). It must be emphasized that such analysis does not involve merely the taking of several different scores relating to the same total performance, but is a true analysis in the sense that *sets* of scores, each of which accounts for *all* the data of a particular type, are taken and used *simultaneously* when assessing the experimental results.

As regards methodology in studies of ageing within industry, our results indicate the need to study *operations* rather than industries, factories, shops, &c., or the classes of operation frequently used as a basis of records and statistics. The implication of this finding is that an adequate understanding of problems of ageing in industry requires a method of classifying operations which is somewhat different from that now customary. It seems essential that operations should be grouped not by stages in the productive process or types of machinery used, or other variables related to factory organization, &c., but by the kinds of receptor or effector demands they make upon the work-people.

Viewing our experimental and industrial studies as a whole, it is clear that, like most work of an exploratory nature, they raise many more problems than they solve. We are continuing in the attempt to clarify some of these, and to extend our research to other problems. In particular, we hope to have the opportunity to make field experiments within industry, as it is only upon these that reliable practical recommendations can be based. At this juncture, however, it does seem justifiable to suggest that further work can profitably be concerned with five practical points:

(*a*) The principle that older people should be moved from heavy to lighter work would appear to be in need of considerable redefinition. It is probable that, although the most strenuous work is unsuitable for older people, over a wide range of moderately heavy operations heaviness as such is a feature of minor importance, especially if the effort required is not continuous. Much more strongly contra-indicated for older people is work where continuous rapid action is required—a feature associated with many light operations.

(*b*) The evidence supports the view, sometimes expressed in the factories we have visited, that older workpeople are more careful and suitable for operations demanding high degrees of accuracy.

(*c*) The early onset of the changes we have observed makes it likely that any alterations which could be made in industrial work (e.g. by improving machine-design or work-layout) which would benefit older workpeople, would also have beneficial effects upon the performances of much younger workpeople, although these effects might not show so much in increased productivity as in a lessening of strain and the consequences of strain.

(*d*) The apparently easier maintenance than acquisition of skill in middle and old age suggests that, from many points of view, the study of methods of retraining older workpeople who for one reason or another have to change their jobs is of the greatest importance, especially with a view to considering the extent to which 'elements' from a former skill are transferred to new tasks, and the effects of such transfer if and when it occurs.

(*e*) The managements of practically all the industrial concerns approached have shown themselves very fully alive to the need for a better understanding of problems of ageing. It would appear that much valuable information is often contained in factory records, but that the value could be greatly enhanced if some modifications were made to the system of recording. In particular a very much fuller knowledge of the capabilities of older people would seem likely to emerge if a system of recording were adopted which had as its basis individual operations classified according to the demands they make upon the people who work them, and which fully recorded the movements of workpeople from one operation to another.

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STATISTICAL APPENDIX

THE nature of the data and the distributions of the scores were such that it seemed best, in most cases, to assess significance by the ranking methods developed by Kendall and extended by Whitfield and others (Kendall 1948, Whitfield 1947). These methods essentially involve the assessment of the covariance between two ranked variables—in our case, the scores under investigation and age. The ranking principle remains even when, as has usually happened, it has been desirable to group subjects into age-ranges or to deal with a dichotomy of 'older' and 'younger'.

The significance assessed is the probability of obtaining, in a universe in which all possible rankings occur an equal number of times, a covariance as great as or greater than that observed. The statistic calculated is the ratio between the observed covariance and the standard deviation of the covariances in the universe. When n is greater than 10 this ratio is distributed approximately as the normal deviate.

The summarized statistics presented below are given under the figure, table, or page numbers in the text where the comparisons concerned are shown.

Experiment 1. Grid-position Matching Experiment

Fig. 1.2. Total events recorded

Subjects under 30 compared with all those over 30:

First 10 minutes	Normal deviate = 2·79	$P < 0{\cdot}01$
Second 10 minutes	Normal deviate = 3·39	$P < 0{\cdot}001$
Third 10 minutes	Normal deviate = 3·00	$P < 0{\cdot}01$

Small errors

Subjects under 30 compared with all those over 30:

First 10 minutes	Normal deviate = 2·26	$P < 0{\cdot}05$
Second 10 minutes	Normal deviate = 3·41	$P < 0{\cdot}001$
Third 10 minutes	Normal deviate = 3·14	$P < 0{\cdot}01$

Successes

Subjects ranked in three age-ranges—under 30, 30–45, and over 45:

First 10 minutes	Normal deviate = 1·91	$P < 0{\cdot}1$ (Not significant)
Second 10 minutes	Normal deviate = 1·85	$P < 0{\cdot}1$ (Not significant)
Third 10 minutes	Normal deviate = 2·17	$P < 0{\cdot}05$

Fig. 1.3. Time to first attempt

Subjects ranked in three age-ranges:

First 10 minutes	Normal deviate = 2·94	$P < 0{\cdot}01$
Second 10 minutes	Normal deviate = 3·29	$P = 0{\cdot}001$
Third 10 minutes	Normal deviate = 3·16	$P < 0{\cdot}01$

Fig. 1.4. Time from making the ball move to stopping it again

Subjects under 30 compared with all those over 30:

First 10 minutes	Normal deviate = 2·81	$P < 0{\cdot}01$
Second 10 minutes	Normal deviate = 2·36	$P < 0{\cdot}02$
Third 10 minutes	Normal deviate = 2·82	$P < 0{\cdot}01$

Time spent on large errors

Subjects ranked in three age-ranges:

First 10 minutes	Normal deviate = 2·36	$P < 0{\cdot}02$

Subjects over 45 compared with all those under 45:

Second 10 minutes	Normal deviate = 2·06	$P < 0{\cdot}05$
Third 10 minutes	Normal deviate = 0·39	Not significant

Experiments 2 and 3. Throwing at a Target

Experiment 2

Fig. 2.1. Far–near inaccuracy in condition C

Subjects over 30 ranked by age-ranges:

Normal deviate = 2·74 $P < 0{\cdot}01$

Fig. 2.2. Differences of far–near inaccuracy between conditions C and B

All subjects ranked by age-ranges:

Normal deviate = 2·22 $P < 0{\cdot}05$

'Teens, twenties, and thirties compared with forties and fifties:

Normal deviate = 2·84 $P < 0{\cdot}01$

Fig. 2.3. Differences of time taken between conditions C and B

All subjects ranked by age-ranges:

Normal deviate = 2·14 $P < 0{\cdot}05$

'Teens compared with fifties:

Normal deviate = 2·85 $P < 0{\cdot}01$

Table 2.2. Percentage of error due to under-correction on the far–near dimension in condition C

All subjects ranked by age:

Normal deviate = 2·59 $P < 0{\cdot}01$

Percentage of error due to over-correction on the far–near dimension in condition C

All subjects ranked by age:

Normal deviate = 2·48 $P < 0{\cdot}02$

Percentage of error due to under-correction on the left–right dimension in condition C

All subjects ranked by age:

Normal deviate = 1·73 $P < 0{\cdot}1$ (Not significant)

Percentage of error due to over-correction on the left–right dimension in condition C

All subjects ranked by age:

Normal deviate = 1·66 $P < 0·1$ (Not significant)

Fig. 2.5. Looking away when picking up chains in condition C

Double dichotomy:

Subjects under and over 30.

Subjects who always or almost always looked, and who seldom or never looked:

Normal deviate = 3·54 $P < 0·001$

Experiment 3

Table 3.1. Looking for chains when there was no need to do so

Subjects in the twenties compared with those in the thirties:

Chains 1–10 Normal deviate = 1·87 $P < 0·1$ (Not significant)
Chains 11–50 Normal deviate = 2·84 $P < 0·01$

Experiment 4. Tracing Figures

Fig. 4.2. Times taken (per subject) to trace ten figures (1–0)

Subjects ranked by age-ranges.

Total times for 15 runs:

Normal deviate = 4·61 $P < 0·001$

Differences between first and fifth runs normal way round:

Normal deviate = 4·32 $P < 0·001$

Differences between fifth run normal way round and first run reversed:

Normal deviate = 2·21 $P < 0·05$

Table 4.2. Times taken (per subject) to write ten figures (1–0) once

Subjects ranked by age-ranges.

Differences between writing normal way round and writing reversed first time:

Normal deviate = 3·05 $P < 0·01$

Differences between writing normal way round and writing reversed second time:

Normal deviate = 3·10 $P < 0·01$

Fig. 4.3. Errors made during all 15 tracing-runs

Subjects in twenties compared with those in thirties.

Positive association between errors and age:

Normal deviate = 1·97 $P < 0·05$

Subjects over 30 ranked by age-ranges.

Negative association between errors and age:

Normal deviate = 3·30 $P < 0·001$

Correlations between time taken and errors made

Age-range	τ	*Normal deviate*	$P <$
20–9	−0·47	2·06	0·05
30–9	−0·42	1·70	0·1 (Not significant)
40–9	−0·51	1·89	0·1 (Not significant)
50–9	−0·53	2·58	0·01
60–9	−0·47	2·31	0·05
70–9	+0·07	0·38	Not significant

(I.e., the quicker subjects tended to be less accurate in all age-ranges except the highest.)

All age-ranges combined (combined probability):
Normal deviate $= 4{\cdot}96 \quad P < 0{\cdot}001$

All subjects ranked by time and by errors:
Normal deviate $= 4{\cdot}70 \quad P < 0{\cdot}001$

Experiment 5. Tracking Experiment

Fig. 5.1. Differences between the two age-ranges in total misalignment

Lowest speed: Normal deviate $= 3{\cdot}43 \quad P < 0{\cdot}001$

The differences for the second highest and highest speeds were tested and also found significant, but the significance-figures are not given as it was felt that the percentage variation between the two age-ranges relative to the accuracy of the scoring device was not sufficient for much reliance to be placed on them.

Fig. 5.3. Increases of distance moved by the subject's pointer within each age-range

Older subjects. The increase from the lowest to the second lowest speed was clearly significant because an increase was shown by every subject.

There were no significant differences above the second lowest speed.

Younger subjects. The increase from the lowest to the second lowest speed was clearly significant because an increase was shown by every subject.

Twenty-two out of the twenty-five subjects showed increases from the second lowest to the middle speed and this increase was shown to be significant: $t = 4{\cdot}58 \quad P < 0{\cdot}001$.

There were no significant differences above the middle speed.

Differences between the two age-ranges in distance moved by the subject's pointer

Lowest speed	Normal deviate $= 2{\cdot}06$	$P < 0{\cdot}05$
Second lowest speed	Normal deviate $= 3{\cdot}69$	$P < 0{\cdot}001$
Middle speed	Normal deviate $= 3{\cdot}24$	$P < 0{\cdot}01$
Second highest speed	Normal deviate $= 3{\cdot}30$	$P < 0{\cdot}001$
Highest speed	Normal deviate $= 2{\cdot}93$	$P < 0{\cdot}01$

Table 5.1. Differences between the two age-ranges in mean phase- (or time-) lag

Lowest speed	Normal deviate = 4·92	$P < 0{\cdot}001$
Second lowest speed	Normal deviate = 4·93	$P < 0{\cdot}001$
Middle speed	Normal deviate = 3·13	$P < 0{\cdot}01$

The mean phase-lag was calculated on the assumption that any such shift would tend to be a constant time-lag which would produce a phase-lag varying inversely with the wave-length of each part of the cam. When ϵ is the actual lag as measured, and X_i is the wave-length of section i of the cam, the phase-lag in radians for that section is

$$\frac{2\pi\epsilon}{X_i}.$$

Therefore the mean phase-lag over all n sections is

$$\frac{2\pi\epsilon}{n}\sum\frac{1}{X_i} = 2\pi\epsilon\frac{1}{HM_x}$$

where HM_x is the harmonic mean of the X_i.

We are indebted to Dr. W. E. Hick for this formula.

Experiment 6. Experiment on Logical Thinking

Table 6.1. The association between age-range and tendency to make comments about material rather than draw deductions

The subjects were divided into two age-ranges—above and below 35 years of age—so that the correlation coefficients given below are for the double dichotomy of age-range and drawing deductions as opposed to making comments.

Set of statements	τ	*Normal deviate*	$P <$
A	0·52	2·18	0·05
B	0·55	3·13	0·01
C	0·42	2·88	0·01
D	0·51	1·65	0·1 (Not significant)
Mean	0·47	5·28	0·001

Table 6.2. The same association with subjects divided into occupational grades

Occupational grade	τ	*Normal deviate*	$P <$
I	0·41	1·78	0·1 (Not significant)
II	0·53	3·60	0·001
III	0·18	. .	. .
Mean	0·48	5·36	0·001

Experiment 7. Solving Electrical Problems

Table 7.1. Time taken

An analysis of variance carried out, after a logarithmic transformation of the data, by the method described in Kendall 1946, vol. ii, pp. 220 seq., gave a variance-ratio of the mean square between age-ranges to the mean

square between subjects treated alike of 16·645. The degrees of freedom were 1 and 27 respectively, so that this figure is well beyond the 0·1 per cent. level of significance.

Readings taken on meter

A similar analysis of variance after logarithmic transformation of the data gave a variance ratio of 6·064, which with the same degrees of freedom is beyond the 5 per cent. level of significance.

Table 7.2. Effect of training-method on performance at first box

Subjects ranked according to number of terminals correctly identified, and dichotomized into two age-ranges.

Training by demonstration: Normal deviate = 2·06 $P < 0{\cdot}05$
Training by written instructions: Normal deviate = 1·15. Not significant.

The above two correlations considered together:
Normal deviate = 2·48 $P < 0{\cdot}02$

Experiment 8. Inspection Task

Fig. 8.1. Difference between subjects over and under 65 in frequency of accepting blocks 7 cm. wide

Normal deviate = 2·52 $P < 0{\cdot}02$

Differences between the age-ranges in frequency of accepting blocks smaller than 7 cm. wide were not significant.

Fig. 8.2. Judgement-times for the first 10 blocks of the first run when this was at subjects' own speed

Subjects ranked in four age-ranges, i.e. under 25, 25–44, 45–64, over 65.

First block	Normal deviate = 2·68	$P < 0{\cdot}01$
Blocks 2–5	Normal deviate = 2·26	$P < 0{\cdot}05$
Blocks 6–10	Normal deviate = 1·68	$P < 0{\cdot}1$ (Not significant)

Subsequent groups of five blocks yielded insignificant results.

Page 107. Judgement-times for the first few blocks of the first run when this was at a speed determined by the machine

Subjects ranked in four age-ranges, i.e. under 25, 25–44, 45–64, over 65.

First block	Normal deviate = 2·64	$P < 0{\cdot}01$
Second block	Normal deviate = 2·10	$P < 0{\cdot}05$
Third block	Normal deviate = 0·48	Not significant

Subsequent blocks and groups of blocks yielded insignificant results.

Table 8.3. Numbers of times no judgement was recorded when blocks were presented at a speed determined by the machine

Subjects ranked in three age-ranges—under 45, 45–64, and over 65.

Subjects whose first run was at 5 seconds per block:
Normal deviate = 1·76 $P < 0{\cdot}1$ (Not significant)

Subjects whose first run was at their own speed:
Normal deviate = 2·07 $P < 0{\cdot}05$

Both the above combined: Normal deviate = 2·85 $P < 0{\cdot}01$

Table 8.4. Blocks judged wrongly out of the first 10 presented

Subjects ranked in four age-ranges.

Blocks presented at subjects' own speed:

Negative association between errors and age.

Normal deviate = 1·97 $P < 0{\cdot}05$

Blocks presented at 5-second intervals:

Positive association between errors and age.

Normal deviate = 2·22 $P < 0{\cdot}05$

Experiment 9. Learning Task

Fig. 9.1. Learning-scores

Time

All subjects ranked by age-ranges:

Normal deviate = 4·48 $P < 0{\cdot}001$

Subjects in twenties, thirties, and forties ranked by age-ranges:

Normal deviate = 1·86 $P < 0{\cdot}1$ (Not significant)

Dichotomy: Subjects in forties and fifties:

Normal deviate = 2·46 $P < 0{\cdot}02$

Time per trial

Dichotomy: Subjects in twenties and thirties:

Normal deviate = 2·23 $P < 0{\cdot}05$

Errors

All subjects ranked by age-ranges:

Normal deviate = 4·20 $P < 0{\cdot}001$

Dichotomy: Subjects in thirties and forties:

Normal deviate = 2·08 $P < 0{\cdot}05$

Fig. 9.2. Relearning-scores

Time

All subjects ranked by age-ranges:

Normal deviate = 4·56 $P < 0{\cdot}001$

Errors

All subjects ranked by age-ranges:

Normal deviate = 4·83 $P < 0{\cdot}001$

Dichotomy: Subjects in twenties and thirties:

Normal deviate = 2·38 $P < 0{\cdot}02$

Table 9.2. Numbers of subjects recalling series correctly at first relearning-trial

Subjects ranked by age-ranges. Dichotomy between those who succeed and those who fail:

Series I. Normal deviate = 4·14 $P < 0{\cdot}001$
Series II. Normal deviate = 3·66 $P < 0{\cdot}001$

Tendency to hit Key 5 (*error*) *rather than Key 1* (*correct*)

The probability that the subjects in the fifties and sixties would have hit Key *5*, rather than Key *1*, the number of times they did as their first in any

trial, was worked out for each subject individually by taking half the sum of the nth and the $(n+1)$th terms of the binomial $(p+q)^m$ where

n = one more than the number of times Key *1* was hit as the first in any trial prior to the first criterion trial

m = the number of times Key *5* or Key *1* was hit as the first in any trial prior to the first criterion trial

p and q both = 0·5.

The probabilities thus obtained for the twenty subjects were combined by the method described by Fisher (1948, p. 99) giving

$$\chi^2 = 67{\cdot}263\text{: degrees of freedom} = 40\text{: } P < 0{\cdot}01$$

Chapter VII. Preliminary Studies in Industry

We give below statistical tests for the tables only. Tests for the age-distributions shown in the figures have not been given because, with such large numbers, any substantial age-trend is significant far beyond the 0·1 per cent. point, whereas several trends which attain significance are not at all substantial, and therefore of little interest.

Table VII.1. Operations divided according to system of payment

Operations ranked by 'mean age of upper half' in decades.
Dichotomy between piece-rates (individual and group together) and time-rates.

Men	Normal deviate = 1·45	Not significant
Women	Normal deviate = 3·10	$P < 0{\cdot}01$

Men and women together (the above probabilities combined)
Normal deviate = 3·51 $P < 0{\cdot}001$

Table VII.2. Rank correlation between mean age of upper half of work-people and length of time-cycle at machine-feeding operations

Men	$\tau = -0{\cdot}036$
Women	$\tau = -0{\cdot}257$ ($P > 0{\cdot}5$)

Table VII.3. Operations divided according to whether or not they involved time-stress

Operations ranked by 'mean age of upper half' in half-decades.
Dichotomy between time-stressed and non-time-stressed:

Men	Normal deviate = 4·06	$P < 0{\cdot}001$
Women	Normal deviate = 3·99	$P < 0{\cdot}001$

Table VII.4. Operations divided according to size of working-group

Operations ranked by 'mean age of upper half' in decades.
Dichotomy between operations with 10 or fewer and 11 or more members:

Men	Normal deviate = 2·55	$P < 0{\cdot}02$
Women	Normal deviate = 0·71	Not significant

Men and women together (the above probabilities combined)
Normal deviate = 2·50 $P < 0{\cdot}02$

Table VII.5. Numbers of persons over and under 50 years of age divided according to size of working-group

Double dichotomy between

(*a*) persons over and under 50

(*b*) operations with 10 or fewer and with 11 or more members:

Men Normal deviate = 3·99 $P < 0{\cdot}001$
Women Normal deviate = 4·51 $P < 0{\cdot}001$

Table VII.6. Operations divided according to type of work

The operations of each type were ranked by 'mean age of upper half' in decades and each type was compared with the remaining types taken together. Men's and women's operations were taken separately. No significant correlations were found.

Table VII.7. Heavy operations divided according to whether or not there was evidence of persons moving away, on account of age, before retirement

Double dichotomy between

(*a*) operations with rigid pacing, and operations not involving time-stress

(*b*) operations on which there was, and was not, evidence of moves:

Men Normal deviate = 3·68 $P < 0{\cdot}001$

Men and women together (totals)

Normal deviate = 4·19 $P < 0{\cdot}001$

Fig. VII.4. Age-distributions of women on inspection and other work

Because of the need to control time-stress, four sets of percentages were worked out thus:

Inspection work (*a*) involving time-stress
(*b*) not involving time-stress.

Other work (*a*) involving time-stress
(*b*) not involving time-stress.

The percentages shown in the figure are the means of (*a*) and (*b*) percentages. The actual (*a*) and (*b*) percentages are shown below:

	Under 30s	*30s*	*40s*	*50s*	*60s*	*70s*	*Total number of persons*
Inspection work							
(*a*) involving time-stress .	37·2	27·4	29·2	5·5	0·6	..	169
(*b*) not involving time-stress . . .	35	25·2	23·6	12·2	2·4	1·6	118
Other work							
(*a*) involving time-stress .	53·2	31·6	11·5	3·4	0·3	..	315
(*b*) not involving time-stress . . .	14	17·8	38·8	16·2	10·1	3·1	134

Fig. VII.5. Age-distributions of men on heavy and other work

This figure was constructed in a manner similar to that of VII.4. The (*a*) and (*b*) percentages are shown below:

	Under 30s	*30s*	*40s*	*50s*	*60s*	*70s*	*Total number of persons*
Heavy work							
(*a*) involving time-stress .	18·9	43·8	29·1	8·1	0·1	. .	736
(*b*) not involving time-stress . . .	23·4	24·2	27·8	15·4	8·5	0·7	976
Other work							
(*a*) involving time-stress .	35·3	37·2	24·1	2·9	0·5	. .	207
(*b*) not involving time-stress . . .	22·1	20·9	24·4	21·5	9·5	1·6	566

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